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HYDRAULIC MODEL INVESTIGATION

TECHNICAL REPORT NO. 116-1

Dworshak Dam
North Fork Clearwater River, Idaho

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Spillways	Aeration Deflectors
Cavitation	Fish Hatchery

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dworshak Dam, located on the North Fork of the Clearwater River near Orofino, Idaho, is the highest straight-axis concrete gravity dam in the United States (717 feet from foundation to 3,300-foot-long crest). The project includes a powerhouse for six Francis-type units (ultimate installation), a selective withdrawal structure upstream from the powerhouse intakes, two spillway bays and three regulating conduits that discharge into a stilling basin, an excavated exit channel, and facilities for migratory fish. The Dworshak National Fish

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Hatchery was constructed to replace spawning and rearing areas for steelhead trout that formerly migrated into the North Fork. The report describes studies accomplished in four hydraulic models and three full-scale test facilities. The investigations presented in this report discuss various problems associated with hydraulic design of the diversion and permanent water-conveyance structures. The tests indicated a need for modification of the originally designed diversion tunnel alignment to remedy unsatisfactory flow conditions existing at both the entrance and exit. Additionally, rock size requirements for cofferdam closure and cable loading on the diversion tunnel closure structure were studied.

Tests and data obtained during development of design of the spillway, regulating conduits, and stilling basin are presented in the report. The design of the skewed regulating conduit entrances were of primary concern in the project. Prototype operation of the outlets resulted in cavitation damage downstream from the valves; an aeration deflector was designed in the model to remedy the problem.

Other items presented include tests on seals for the eccentric-trunnion tainter gate valves in the regulating conduits, fish hatchery appurtenances, and measurements of torque on torsion bars of pressure relief panels in the powerhouse selective withdrawal system.

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PREFACE

A comprehensive model of the Dworshak project and a model of the right regulating conduit were authorized 4 February 1963 by the Office, Chief of Engineers, at the request of the U.S. Army Engineer District, Walla Walla. The initial authorization was extended to studies of a powerhouse fishway diffuser; a powerhouse selector gate pressure-relief panel; regulating conduit tainter valve seals; and fish hatchery jet headers, aerators, and deaerators.

The studies were made during the period December 1963 to July 1972 at the North Pacific Division Hydraulic Laboratory under the supervision of Messrs. H. P. Theus and P. M. Smith, Directors of the Laboratory, and A. J. Chanda and R. L. Johnson, Chiefs of the Hydraulics Branch. Engineers in immediate charge of the various models were Messrs. B. M. Bolme, G. H. Gautschi, W. Hickerson, R. L. Johnson, L. Z. Perkins, and P. M. Smith. They were assisted by Messrs. F. S. Bahler, G. D. Bocksler, and D. E. Fox. This report was prepared by Messrs. Smith and Perkins and edited by Mr. Theus.

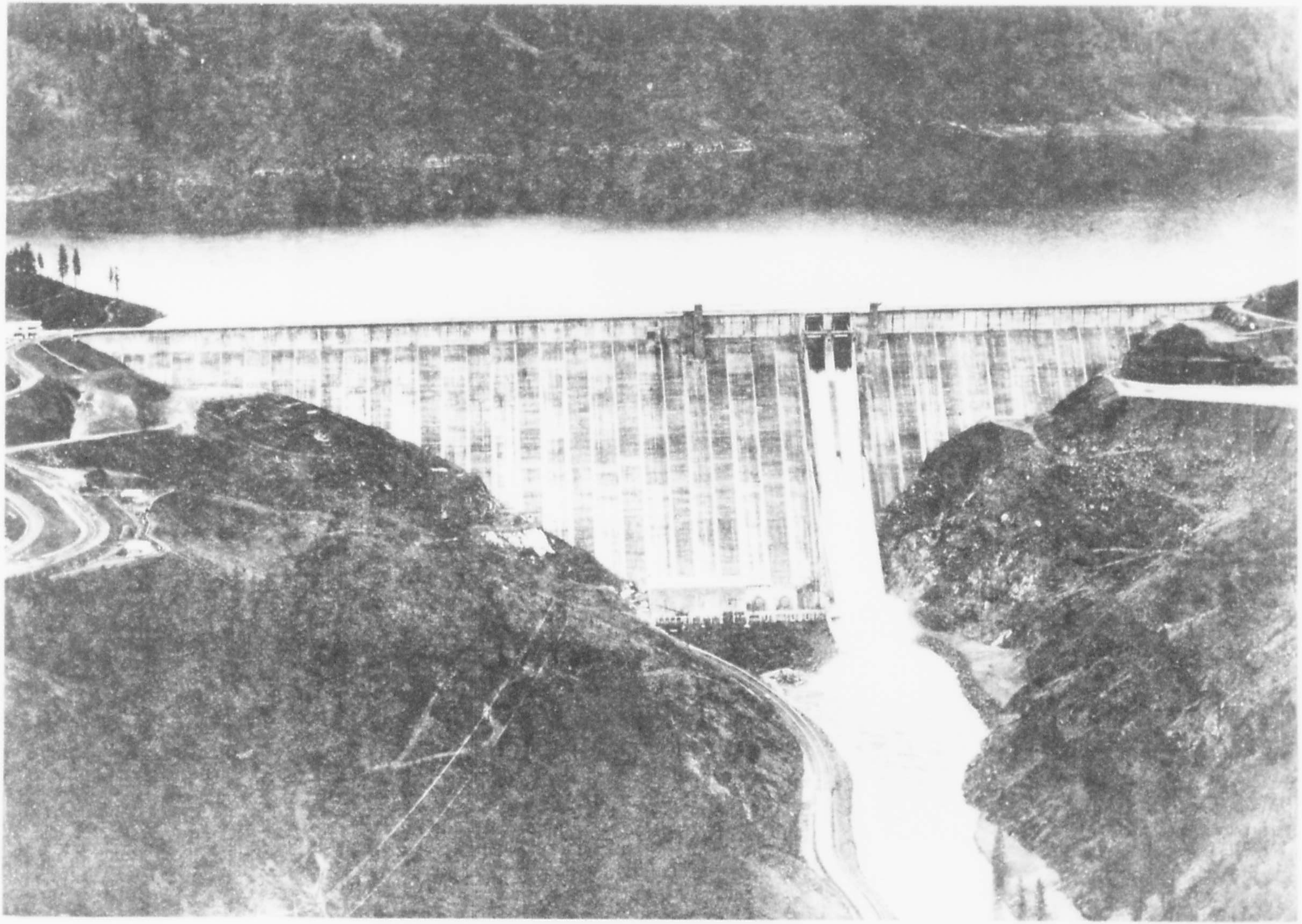
During the course of the studies, Messrs. J. H. Douma and S. B. Powell of the Office, Chief of Engineers, H. A. Smith of the North Pacific Division, and G. C. Richardson, A. L. McCormmach, and R. O. Pearce of the Walla Walla District visited the Laboratory to observe flow conditions in the models, to discuss results of the tests, and to correlate these results with design work that was in progress. Flow conditions were demonstrated for representatives of State and Federal fisheries agencies and the Potlatch Timber Company, Lewiston, Idaho.

CONTENTS

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles (U. S. statute)	1.609344	kilometers
square feet	0.092903	square meters
feet per second	0.3048	meters per second
feet per minute	0.3048	meters per minute
cubic feet per second	0.0283168	cubic meters per second
tons (short)	907.185	kilograms
inches	25.4	millimeters
acre-feet	1,233.48	cubic meters
gallon per minute	0.06308	liters per second
pounds (mass)	0.4535924	kilograms
kips	4,448.0	newtons
inches per minute	0.423	millimeters per second



Aerial View of Dworshak Dam

DWORSHAK DAM

NORTH FORK CLEARWATER RIVER, IDAHO

Hydraulic Model Investigations

PART I: INTRODUCTION

The Prototype

1. Dworshak Dam (plate 1) is located on the North Fork of the Clearwater River 1.9 miles* upstream from the confluence with the Clearwater River near Orofino, Idaho, as shown in figure 1. The 53-mile-long reservoir upstream of the dam has a shoreline of 175 miles and a usable storage capacity of 2,016,000 acre-feet. The project is operated as a unit in the comprehensive plan for development of the Columbia/Snake River resources for flood control, hydroelectric power, navigation, irrigation, and other uses.

2. The dam is the highest straight-axis concrete gravity structure in the United States; the roadway deck is at elevation 1613--717 feet above bedrock and 13 feet above normal maximum operating pool elevation 1600.** The spillway, regulating conduits, and stilling basin are adjacent to the left bank; a powerhouse for six Francis-type units and facilities for collecting, holding, and transferring migratory fish are adjacent to the right bank (plate 1). Two 90-MW powerhouse units and one 220-MW unit were installed initially. With pool elevation 1600 and a 115-percent overload, the units discharge approximately 10,000 cfs. Three more 220-MW units are to be added later (ultimate powerhouse capacity 1,060 MW; discharge 25,000 cfs). A selective withdrawal structure on the upstream face of the dam over the penstock intakes permits flow to be drawn from different strata in the reservoir to meet water quality requirements downstream.

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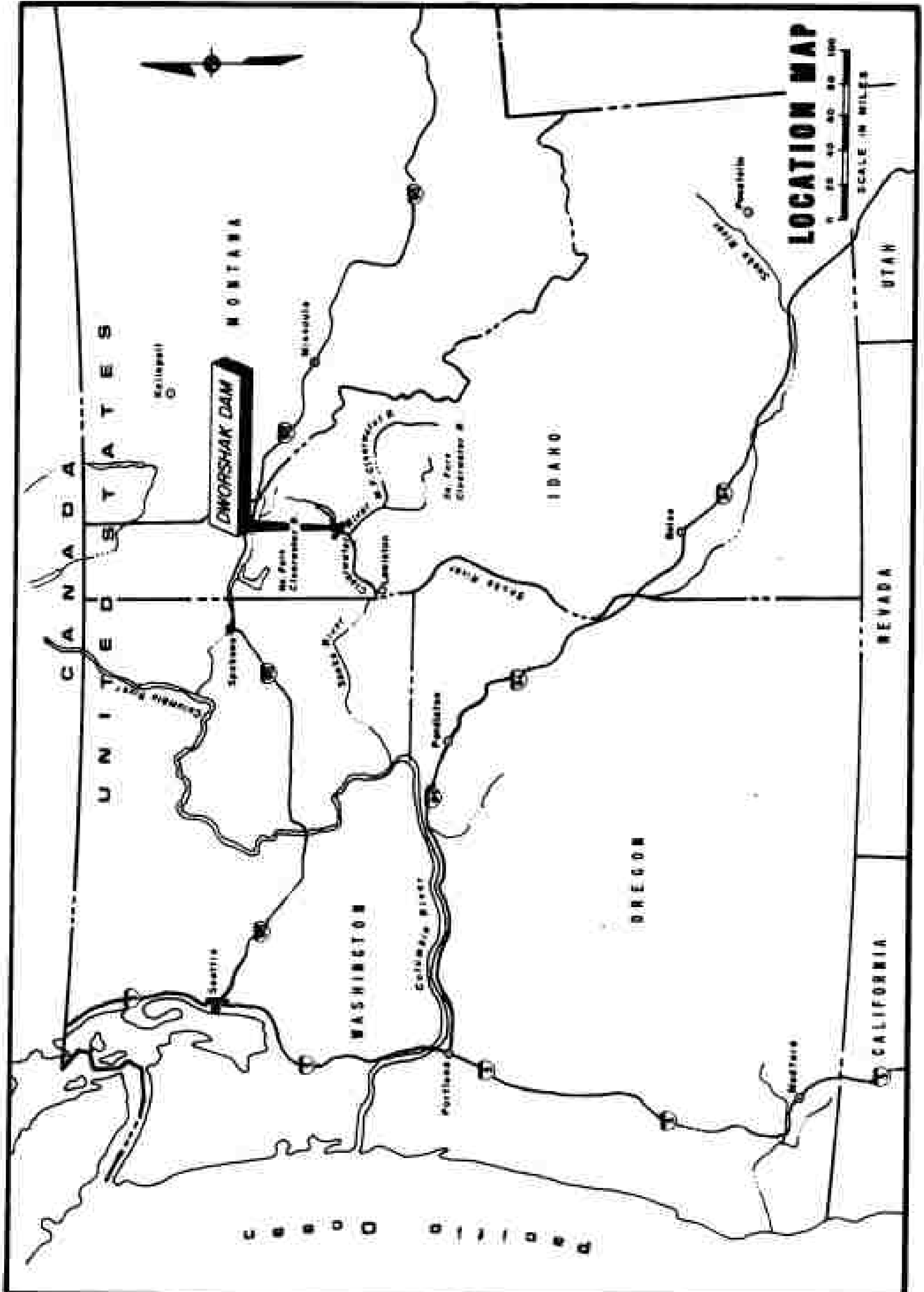
* A table of factors for converting U.S. customary units of measurement to metric (SI) units is shown on page iv.

** All elevations are in feet above mean sea level.



LOCATION MAP
SCALE IN MILES
DWORSHAK DAM
CANADA
UNITED STATES
MONTANA
IDAHO
WASHINGTON
OREGON
UTAH
NEVADA
CALIFORNIA
Pacific Ocean
Columbia River
Snake River
Seattle
Portland
Spokane
Boise
Missoula
Kalispell
Pendleton
Lewiston
Medford

Figure 1

3. The spillway consists of two 50-foot-wide bays with crest elevation 1545, tainter gates approximately 56 feet high, a center pier 22 feet wide, and a tapered chute leading to the 114-foot-wide by 280.53-foot-long stilling basin at elevation 931 (plate 2). Details of the spillway crest, pier, and abutments are shown on plate 3. The spillway weir profile corresponds to the U.S. Army Corps of Engineers' high dam shape with a design head (45.402 feet) equal to approximately 0.83 of the total maximum head on the crest. Three 12- by 17-foot regulating conduits with upstream tainter valve control empty into the spillway chute at elevation 1219.89. The two outside conduits are skewed in plan to place the emergency gate slots in the spillway abutments. The original spillway design flood of 190,000 cfs consisted of a combined spillway flow of 150,000 cfs and conduit flow of 40,000 cfs at pool elevation 1600. As a result of routing studies, the project design discharge was later increased to 254,000 cfs at pool elevation 1610.5 and then reduced to 230,000 cfs at pool elevation 1604.9 (powerhouse 8,000 cfs, regulating conduits 41,000 cfs, and spillway 181,000 cfs). The stilling basin was designed to provide good energy dissipation for 40,000 cfs of the regulated standard project flood of 45,000 cfs with 5,000 cfs passing through the powerhouse. Sweepout of the hydraulic jump during high discharges was acceptable because of the rare occurrence of flows greater than 45,000 cfs and because short periods of sweepout would not endanger the structure.

Purposes of Investigations

4. Although the project was designed in accordance with approved design practice, model analysis of various elements was necessary in the interests of economy, performance, and safety. The original purposes of the model studies were to observe effects of successive construction stages on conditions affecting fish migrations, log passage, and tunnel closure; to check the adequacy of designs for the spillway, stilling basin, regulating conduits, and excavated tailrace; and to develop revisions found necessary as a result of the model studies.

The scope of the studies was later extended to include tests of the tainter valve seals; powerhouse fish collection system; fish hatchery jet headers, aerators, and deaerators; and powerhouse selector gate pressure-relief panels.

PART II: THE MODELS

Description

5. Hydraulic features of Dworshak project were studied in a 1:50-scale comprehensive model, a 1:20-scale model of the right regulating conduit, a 1:10-scale model of a typical powerhouse fishway diffusion chamber, and a 1:5-scale model of a powerhouse selector gate pressure-relief panel. Full-scale tests were made of rubber seals for the regulating conduit tainter valves and of jet headers, aerators, and deaerators for the fish hatchery. The test facilities are described as the respective studies appear in this report.

6. Water was pumped to the models from recirculating tanks and was measured by means of V-notch weirs or calibrated orifices in the supply lines. Standard laboratory instruments and procedures were used to measure velocities, water surface elevations, pressures, and forces. Visual observations of flow conditions and the behavior of test materials were augmented by photographs.

Interpretation of Model Results

7. Model measurements were converted to prototype values with equations of similitude based on the Froude model law. Although converted model pressures lower than -34 feet of water have no prototype significance beyond indicting vaporization, they show relative pressure conditions in the models. Water manometer pressures lower than -10 feet of water in the models indicated areas where cavitation damage might occur in the prototype. Air entrainment, which is highly developed in the prototype, was not reproduced to scale in the models; therefore, the effects of air bulking on chute and stilling basin wall heights were not determined in the model.

PART III: DIVERSION

The Model

8. Diversion of the river during construction was studied in the 1:50-scale comprehensive model, which reproduced the riverbed and overbank topography below elevation 1125 between River Mile (RM) 1.0 and RM 2.6 (figure 2 and plate 4). The topography was molded of cement mortar to sheet metal templates. The model was verified by adjusting the riverbed roughness until prototype water surface profiles and velocity measurements for river discharges between 1,160 and 20,900 cfs were reproduced. The prototype data were extrapolated to provide tailwater rating curves at North Fork RM 1.1 for Clearwater River discharges between 2,000 and 100,000 cfs (plate 5).

9. Comparisons of model to prototype water surface profiles for natural conditions and river discharges between 1,160 and 20,900 cfs are shown on plate 6. Water surface profiles in the model and computed profiles for various combinations of North Fork and Clearwater River discharges are shown on plate 7. The maximum difference between model and computed water surface profiles occurred from RM 1.60 to 1.99 (a reach which would be between future cofferdams). Differences of 0.8 foot or less existed in the section of the model downstream from the proposed diversion tunnel exit at RM 1.60.

Diversion Tunnel

Design Requirements

10. The plan for diversion of the river during construction consisted of two cofferdams and a tunnel through the left abutment. The hydraulic requirements were:

a. To pass a 25-year flood of 68,000 cfs without overtopping the upstream cofferdam with a top elevation of 1062.

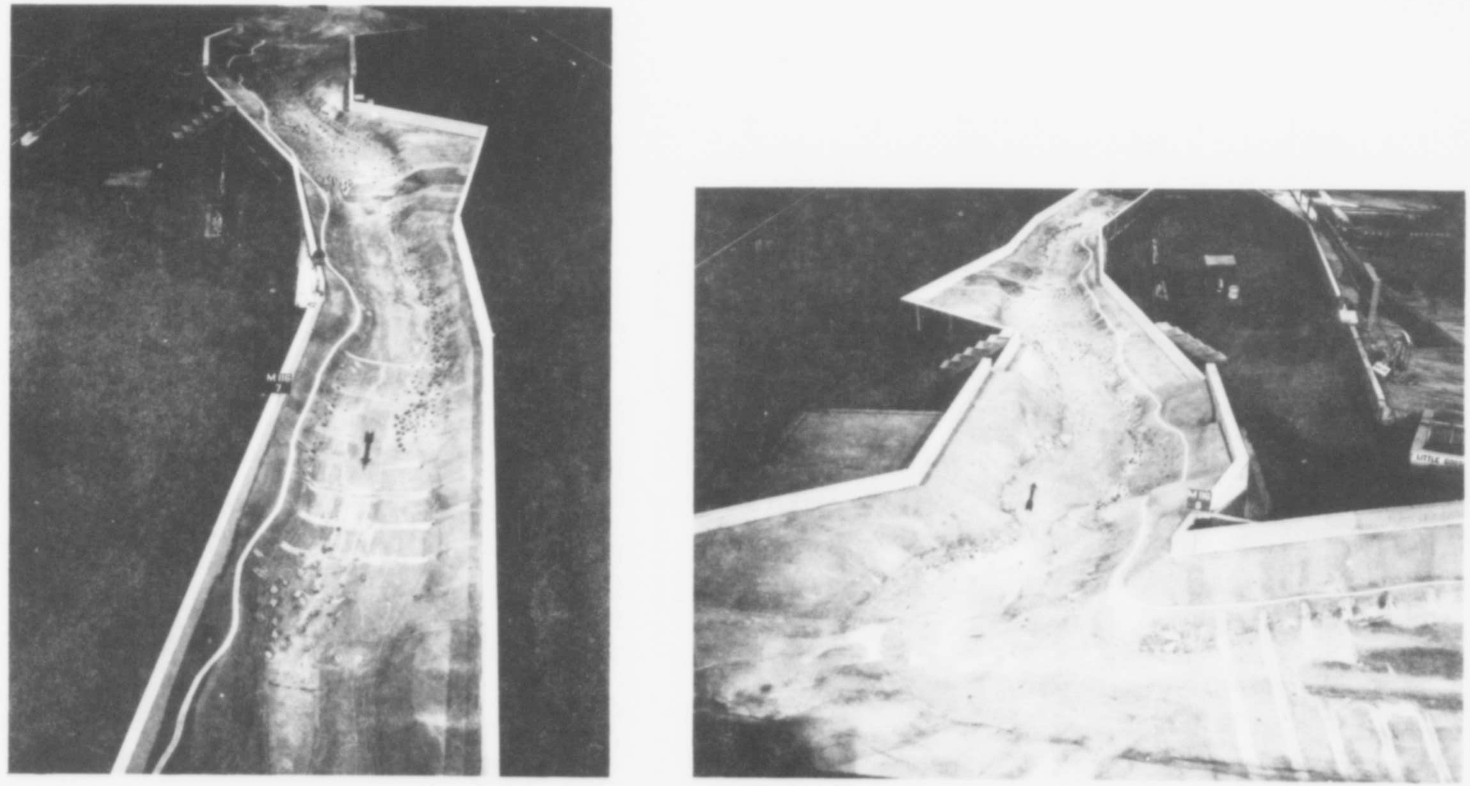


Figure 2. Drybed views of model showing channel roughness after verification.

b. To accommodate a log drive each spring with river discharges of 10,000 to 44,000 cfs (5-year flood) and with a minimum clearance of 6 feet between the water surface and the roof along the center of the tunnel.

c. To pass migratory fish--principally steelhead trout--upstream during low discharges.

11. The requirements for passing logs necessitated lining the tunnel to prevent logs from catching against rough surfaces and blocking the tunnel. Computations indicated that a concrete-lined, 40-foot-diameter horseshoe-shaped tunnel on a slope of 0.004 would be adequate. The concrete lining reduced the cross sectional area needed to pass the design flow and was expected to minimize erosion caused by velocities as high as 52 fps. Lining the tunnel increased velocities to the extent that a fish block would occur within the tunnel with all but the smallest discharges. To prevent fish from entering the tunnel, the outlet apron was sloped upward to spread the flow uniformly over the lip and to create a drop that would produce fish-blocking velocities. Fish were to be trapped at the right side of the apron and diverted into the tunnel during low flows and hauled upstream during higher flows. A separate small tunnel for fish passage was also considered.

Plan A (Original Design)

12. A layout of Plan A, the first plan tested, is shown on plate 8. Details of the tunnel, intake channel, and outlet channel are shown on plates 9, 10, and 11, respectively. The downstream cofferdam cells in the model were formed of sheet aluminum and filled with concrete, the diversion tunnel was made of acrylic plastic, and the tunnel outlet basin was made of waterproofed plywood.

13. Flow conditions at both ends of the tunnel were unsatisfactory. The concentration of flow on the left side of the approach channel caused severe turbulence and high velocities at the tunnel

entrance (photographs 1 and 2). Logs were forced toward the left side of the approach channel by flow over a sharp ridge along the top of the excavation. At the tunnel outlet, high-velocity flow swept out of the excavated area, crossed the river channel, and impinged against the right bank. Two standing waves that formed in the excavated basin moved downstream as discharge increased.

14. Flow within the tunnel is shown in photograph 3 for discharges of 20,000 to 35,000 cfs. Standing waves formed at flows greater than 20,000 cfs and were maximum for discharges between 30,000 and 35,000 cfs. At 35,000 cfs, flow filled the upstream portion of the tunnel and open-channel flow occurred in the downstream portion. With the tunnel filled, air was drawn into the intake by vortexes with discharges between 43,500 and 68,000 cfs.

15. Although the exact discharge required to overtop the upstream cofferdam (elevation 1062) was not determined, observations indicated that it would occur between 65,000 and 68,000 cfs. Water surface elevations in the forebay (gages 5, 6, A, and B) were recorded for river discharges between 5,000 and 60,000 cfs (table A). The observed elevations were corrected for differences in roughness of prototype and model tunnel walls for discharges of 5,000, 10,000, and 60,000 cfs. In the prototype the other discharges would be controlled at the tunnel entrance and were corrected for critical depth at that location. The "n" value of the plastic model walls was 0.0077 (prototype value 0.0148), as compared with an average prototype "n" of 0.012 (model value 0.0062) for concrete walls.

Entrance Plan B and Outlet Plans B and C

16. Following tests of the original design, the upstream approach was streamlined by means of a 45-degree curve along the left bank and a disposal fill was placed to elevation 1062 along the right bank (Plan B, plate 10). Two proposals to improve the outlet channel were studied

(plate 11). In Plan B, a curved 100-foot-wide by 600-foot-long pilot channel was excavated to elevation 962 from a point 440 feet below the downstream portal. In Plan C, a trapezoidal-shaped stilling basin at elevation 952 was added to the Plan B design.

17. Although the Plan B entrance reduced the pool elevation 2.3 feet at 45,000 cfs, topography upstream from the intake caused relatively high velocities along the disposal fill. Log passage was confined to a narrow zone adjacent to the left wall of the entrance. Flow within the tunnel was similar to that with the Plan A entrance. Standing waves in both revisions of the outlet channel occurred in about the same location and were of the same magnitude as those in the original channel. Although the stilling basin of the Plan C outlet produced improved flow conditions, velocities that crossed the river channel were still sufficiently high enough to block the upstream passage of migratory fish.

Plan B Tunnel, Plan C Entrance, and Plan D Outlet

18. Based on results of the previous tests, the tunnel alinement was changed to place the intake and outlet channels more in line with the valley walls (Plan B, plate 8). The horseshoe shape and 40-foot diameter were retained. To maintain at least 6 feet of clearance between the water surface and the tunnel roof at a riverflow of 44,000 cfs, the tunnel entrance was 35 feet wide and 50 feet high (plate 12). A 40-foot long transition connected the entrance to the 40-foot horseshoe section. This transition--designed to create a critical-depth control at the tunnel entrance for discharges from 10,000 to 55,000 cfs--would cause drawdown and provide the desired clearance. The open channel upstream from the entrance portal included a transition from a trapezoidal section to a 35-foot-wide rectangular section. The channel was designed to lower the water surface on a gradual slope upstream from the tunnel entrance and ensure clearance for logs at flows less than 44,000 cfs.

19. The revised tunnel alignment allowed the number of cofferdam cells at the outlet to be reduced from six to four (Plan D outlet, plate 13). The outline of outlet Plans A, B, and C was retained, and a 440-foot-long slope, 200 feet wide at the downstream end, was excavated downstream of a 150-foot-long stilling basin at the end of the outlet apron. The long, broad slope was intended to distribute flow across the river and reduce velocities along the right bank.

20. No adverse pressures in the tunnel were measured at the piezometer locations shown on plate 12 except at piezometer 4 in the entrance roof with a discharge of 60,000 cfs. Computations of prototype conditions with the correct wall roughness indicated that drawdown would occur at the prototype entrance with that discharge and the low pressure area in the model would be exposed to air in the prototype. Flow conditions at the tunnel entrance were satisfactory, although differences in topography along the entrance walls caused the center of flow to be 5 to 10 feet left of the tunnel axis. Observed model water surface elevations and model pool elevations corrected for differences in model and prototype tunnel roughness indicated that freeboard on the elevation 1062 upstream cofferdam was 6.5 feet at 65,000 cfs. Overtopping of the model cofferdam was imminent at this discharge. Flow in the tunnel was similar to that in previous tests; waves occurred for open channel discharges greater than 5,000 cfs. During a discharge of 30,000 cfs, a standing wave at station 11+70 almost filled the tunnel; 34,000 cfs was the upper limit for open channel flow in the model. Computations indicated that the upper limit in the prototype would be approximately 55,000 cfs. Since the effects of greater roughness in the model produced a Froude number of approximately one for open-channel flows of 10,000 cfs and greater, the waves were undular. The Froude number in the prototype would be slightly greater than one. Flow would be supercritical with some undular wave action. Computations indicated that clearance between the water surface and roof of the prototype tunnel with a discharge of 44,000 cfs would be 8 feet.

21. The Plan D outlet was not satisfactory for fish and log passage. The stilling basin did not retain a hydraulic jump during discharges below 14,000 cfs, and return flow along the right bank and cofferdam cells occurred at all flows. Velocities along the left wall were higher than they were in other areas of the stilling basin (plate 14). Logs carried by flow from the right side of the stilling basin were caught in the return flow, reentered the main flow, and collided with logs emerging from the tunnel.

Outlet Plans E to I

22. The Plan E outlet channel (plate 13) was excavated to elevation 962 and connected to the stilling basin by a 1V on 4H slope. A strong hydraulic jump formed in the basin during discharges of 10,000 to 46,000 cfs, and logs were tumbled and thrown together. In addition, logs that reentered the basin in flow along the cofferdam struck other logs broadside. Conditions for fish passage were improved, and a fairly distinct line of attraction velocities (6 to 10 fps) existed along the right side of the flow from the river to the fish entrance. Tests of two fishway entrance plans (plate 15) indicated that an entrance normal to the outlet flow (Plan E-2) provided better penetration of attraction flow into discharge from the tunnel (plate 16).

23. At this point in the model study, the following criteria for log and fish passage were adopted:

a. To prevent collisions between logs from the tunnel and those delayed by the jump and in flow along the cofferdam cells, no hydraulic jump should occur between 10,000 and 46,000 cfs.

b. Distribution of flow across the channel between the left wall and the cofferdam should reduce or eliminate return flow along the cells and flow that would divert fish from the fishway entrance.

c. Velocities along the left wall should exceed 15 fps to prevent upstream passage of fish on that side of the outlet. Velocities along the right side of the flow should be between 6 and 10 fps to lead fish into the fishway.

d. Velocities along the right bank downstream from the outlet should be less than 10 fps for discharges to 20,000 cfs to provide a way for fish to pass upstream.

24. The outline of the Plan F outlet (plate 17) was the same as that for Plan E (plate 13) except that the stilling basin was eliminated and the entire channel floor was excavated to elevation 962. The stippled concrete floor of the outlet channel reproduced a prototype roughness "n" of 0.028. Seven 3-foot-high by 5-foot-wide sills, 20 feet apart, were extended entirely across the channel immediately downstream from the outlet apron. The sills were included to dissipate energy and transition from supercritical to subcritical flow without causing a hydraulic jump. Flow conditions for discharges of 10,000 to 30,000 cfs were considered satisfactory (plate 18).

25. The outlines of outlet Plans G through I were the same as that of Plan F, but the bottom of the elevation 962 excavation was roughened to simulate rock excavation ("n" = 0.045 to 0.050). Plan G had a 3-foot-high by 15-foot-wide sill across the channel near the apron; Plan H had none (plate 17). Plan I had four 3-foot-high by 10-foot-wide sills placed 30 feet apart (plate 20). Flow directions and velocities were satisfactory for fish passage with all three plans (plates 19 and 21); however, conditions for log passage were best with Plan I. There was no return flow along the cofferdam cells in the Plan I outlet to return logs to the vicinity of the outlet apron and fishway.

Plan J Outlet (Final Design)

26. The Plan J outlet included realigned cofferdam cells, a wider fishway, and channel excavation slopes and roughness that represented overburden along most of the left bank and floor (photograph 4 and plate 20). Four 3-foot-high by 10-foot-wide sills, similar to those in Plan I, were extended across the channel from the left wall to the cofferdam cells.

27. Flow conditions with discharges of 3,000 to 68,000 cfs are shown on plates 22 through 24. Conditions for fish passage were satisfactory for discharges up to 20,000 cfs. In flows below 8,250 cfs, a weak hydraulic jump formed at the downstream end of the tunnel outlet apron and velocities in the outlet channel varied from 2 to 10 fps. Discharge from the fish collection chamber was drawn into the end of the jump approximately 15 feet from the fishway entrance. With higher flows in which no jump formed, penetration of attraction flow from the fishway into discharge from the outlet was acceptable. A distinct path of attraction flow existed along the right side of the channel from the open river to the fishway entrance, and a passage block occurred along the left bank. With 68,000 cfs, the design discharge for the upstream cofferdam, the downstream cofferdam had 10 feet of freeboard.

28. Conditions for log passage were good. There was no hydraulic jump to tumble the logs and no return flow to carry logs upstream to collide with other logs in the outlet channel. Experiments indicated that only the two upstream sills were required to spread flow across the channel for discharges of about 10,000 cfs. All four sills were needed when the flow was greater than 20,000 cfs. The length and spacing of the sills were important, since any decrease in length or spacing decreased their effectiveness. Although bottom velocities on the channel floor and along the left bank were higher than desired, no practical way was found to reduce velocities and still maintain satisfactory conditions for log passage at the higher flows.

Removal of Temporary Dikes

29. The diversion tunnel contractor planned to use a protective dike around the upstream end of the tunnel heading and to have a spur dike upstream on the left bank and an excavation to elevation 975 in the right bank to direct flow away from the work area. Since only a section of dike across the entrance channel was to be removed to allow flow to enter the completed tunnel, the remaining section and the spur dike might affect flow conditions during diversion.

30. As reproduced in the model, the gap in the main dike was 50 feet wide (the same width as the entrance channel) and the sides were sloped 1 vertical on 2 horizontal. The dikes, upstream cofferdam, tunnel entrance, and other elements that were installed for the study are shown on plates 25 to 27.

31. Flow conditions adjacent to the dikes were observed for river discharges of 5,000 to 65,000 cfs. Velocities at the spur dike were less than 3 fps, and velocities at the main dike were 6 fps or lower at all flows. No scouring of the dike material was indicated by this range of velocities. Log passage was slightly better with the dikes than without them. The logs floated near the right bank as they approached the bend upstream from the tunnel, and nearly all followed the flow through the gap in the main dike. With a discharge of 20,000 cfs, large logs sometimes grounded on top of the main dike; however, a slight increase in discharge or wave action dislodged them. Since the pool elevation did not increase with the 65,000-cfs discharge, a 50-foot-wide opening through the dike was adequate.

Upstream Cofferdam Closure

32. Construction of the main cofferdams was scheduled to begin immediately after the diversion tunnel was completed and temporary dikes at the upstream and downstream ends of the tunnel were breached.

Cofferdam placement and dewatering were scheduled for the low-flow period of September through December 1964. Mean daily discharges in the North Fork of the Clearwater River had not exceeded 5,000 cfs during the months of September and October and had seldom exceeded 7,000 cfs during November and December. Construction of the upstream cofferdam was to begin by end-dumping a closure fill of quarry-run rock from the right bank.

33. The size of rock required for closure and flow conditions for river discharges of 7,000 and 10,000 cfs was checked in the model. Closures were made by means of end-dumped fills with 24- and 60-foot-wide tops at elevation 990 and side slopes of 1 vertical on 1.25 horizontal. The closures were made with crushed granite-gneiss rock from the damsite that represented prototype rocks weighing 30 to 1,570 pounds. Eighty percent of the stones used in the model represented prototype stones weighing less than 500 pounds and 99 percent weighed less than 1,000 pounds (plate 28). A comparison of model and prototype quarry-run rock showed that the prototype contained the same size range but a larger proportion of small material (fines). The material, dumped in 20-cubic-yard loads and pushed by bulldozer over the end of the fill, stood initially on a 45-degree slope and then sloughed to approximately 1 vertical on 1.25 horizontal. During closures at other projects, the sloughing has been hazardous to bulldozer operators. Since the model fill was probably more permeable than the prototype fill, the model was made almost impermeable by placing plastic sheeting over the upstream face of the fill as construction progressed. This action provided a safety factor by creating a slightly higher closure head than would occur in the prototype.

34. Flow conditions before closure are shown on plate 29. Plates 30 and 31 show conditions with closure gaps of 50 and 25 feet, respectively, with the 24-foot-wide fill. Although heads of 9 and 14 feet from gage A to tailwater would be required to pass 7,000 and 10,000 cfs, respectively, through the tunnel, the cofferdam closures

were not made against these heads. The steel cells of the downstream cofferdam which would be in place during upstream closure produced additional backwater at the closure site. Also, a berm of fill material that formed downstream from the gap increased head losses and lowered velocities in the closure section. All the rock in the berm fell within the limits of the completed cofferdam. The berm was essentially complete when the fill was closed to a 25-foot gap with a flow of 7,000 cfs and to a gap of 50 feet with 10,000 cfs. The quantities of rock required to complete each stage of fill construction for the 24-foot-wide fill are shown on plates 30 and 31. Closure of the 60-foot-wide fill was accomplished more easily than that of the 24-foot-wide fill. The longer closure gap caused almost all of the material to be retained within the width of the closure fill. The tests showed that the entire closure would be made with the quarry-run rock in flows of 7,000 and 10,000 cfs.

35. The water surface elevations shown on plates 30 and 31 were not corrected for model tunnel roughness because the correction would have been 0.8 foot or less. Since model tunnel roughness was greater than would exist in the prototype, the test closures were made against slightly greater heads and discharges through the gap than would occur in the prototype. When corrected, the upstream water surface would be only 0.4 foot below the top of the elevation 990 fill with a river discharge of 10,000 cfs.

Closure of Diversion Tunnel

Original Plan

36. The diversion tunnel was scheduled to be closed immediately after the annual log drive in the spring or early summer--a year in advance of project completion. Initial plans called for a concrete arch closure gate capable of withstanding a hydrostatic head of 480 feet. The gate was to have been built on a platform above the

tunnel intake and lowered into position by means of a hydraulic system. The cost of constructing and placing a one-piece gate over the tunnel entrance made this plan impractical. A hydraulic system for this purpose was estimated to cost one-half million dollars.

Alternative Plan

37. An alternative plan was tested in the model. Initial closure of the diversion tunnel was to be made by lowering five racks or bulkheads--each 6 feet 6 inches wide by 9 feet 6 inches high by 39 feet 8 inches long weighing 38.6 tons--in gate slots at the face of the upstream portal. Details of the closure racks are shown on plates 32 and 34. These racks would be lowered from a work area at elevation 1080 on the hillside over the entrance portal. A rockfill with earth blanket was to be placed on the upstream side of the racks to complete initial closure. The upstream 75 feet of the tunnel was to be plugged with concrete for final closure. The principal purpose of the tests was to determine whether two 45-ton mobile cranes could safely lower the racks into position during river discharges of 20,000 cfs and less.

38. Test Apparatus: The model test apparatus consisted of one brass and aluminum rack with each member built to scale (the test rack), four plastic racks with correct overall dimensions and openings for flow, a motor-driven suspension system that simulated the cranes and cables, a force-measuring gage, and a rack position indicator (plate 33). The tunnel entrance with the racks in the slots is shown in photograph 5. The slots were constructed to provide prototype clearances of 1 inch at each end of the racks and 1-5/16 inches between the upstream face of the racks and the slots. The downstream faces of the model slots were lined with Teflon to ensure that the friction factor would be minimized. The friction factor of the brass rack sliding on wet Teflon was found to be 0.09; the estimated friction factor of wet steel sliding against steel was 0.20 to 0.25.

39. The cranes were simulated by a triangular bracket driven by two electric motors with prototype lowering speeds of 2 and 5 fpm. The cables were simulated by wires suspended from horizontal flat springs that were adjusted to have an elongation of 3.9×10^{-8} feet per foot per pound (prototype). This was the estimated unit elongation of 6-by-37 IWRC cable having a modulus of elasticity of 18 million psi. The rack position and measured cable loads (hydraulic downpull, buoyancy, and friction) were recorded on oscillograms. The dry weight of the rack--38.6 tons--added to the measured forces equaled total loads on the cables.

40. Cable Loads: Cable loads which were measured with racks of original design being lowered at a speed of 2 fpm into flows of 3, 5, 10, and 20 thousand cfs are shown on plate 35; rack 1 was the bottom rack (position 1). A maximum instantaneous load of 324 kips occurred as the third rack was lowered into a discharge of 20,000 cfs. With lesser flows, maximum instantaneous loads (141 kips at 3,000 cfs, 179 kips at 5,000 cfs, and 266 kips at 10,000 cfs) were measured as the second rack was placed. These loads indicated that 5,000 cfs was the upper limit for closing the tunnel if two 45-ton cranes were used to lower the closure racks. The loads were maximum when flow began to spill over the rack and was 1 to 3 feet deep at the upstream edge. The fourth rack was not submerged during placement in a flow of 10,000 cfs, and cable loads were less than they were with the first three racks. The fifth rack was placed in the dry. Increasing the lowering speed to 5 fpm had little effect, and the load did not change when a rack was stopped in the flow. The hydraulic load on the first rack was upward during the last 1 to 3 feet of lowering; however, the net load was downward.

41. The racks exhibited no tendency to oscillate as a result of flow passing over and under them but the downward movement was not steady. This action did not cause the racks to jam in the slots or interfere with the lowering. The maximum rate of loading change caused by the irregular motion was about 48 kips per second (prototype).

42. Efforts to Reduce Cable Loads: To relieve low pressures below the bottom beam and reduce downpull forces on the rack, two patterns of holes were cut in the bottom horizontal plate (plate 34). The effects of holes in the bottom plates of racks in several positions were slight at a flow of 3,000 cfs, but at other flows the holes decreased the load (plates 36 and 37). The greatest reduction was obtained with holes in the three lowest plates--flow across the top of the rack was changed and a slight increase in downpull occurred when holes were cut in the top plate. Increasing the rack lowering speed to 20 fpm had no appreciable affect on loading. There was no significant increase in the discharge at which the racks could be lowered into the intake without exceeding the capability of two mobile hoists.

43. One-, 2-, or 3-foot-long lips attached to the downstream, bottom edge of the original rack were not satisfactory. Although maximum cable loads (occurring when the racks were just overtopped) were reduced by the lips, uplift forces that prevented the racks from seating were created. The heights above the channel invert at which racks in position 1 would stop descending are shown by the intersection of the load curves and the zero-load line on plates 38 and 39.

Adopted Plan

44. As prototype construction progressed, it was possible to schedule closure of the tunnel during the relatively low flow prior to the spring flood rather than during the higher flows of the flood recession as originally scheduled. The adopted scheme, though not tested in the model, consisted of a gate made up of 11 sections that could be handled by standard heavy construction equipment. The sections were steel frames that were filled with concrete after placement. The 26-foot-high bottom section contained five 5.5- by 5.5-foot orifices with remote-controlled slide gates on the upstream side. The gates were open during placement of the closure gate sections to allow discharges as large as 2,800 cfs through the orifices under a head of

25 feet or less. The sluice gates were closed when all gate sections were in place and filled with concrete; then the tunnel plug, designed to withstand the ultimate maximum head of 630 feet, was constructed.

PART IV: COMPLETED STRUCTURES

The Model

45. After tests of the diversion phase, the 1:50-scale comprehensive model was revised (plates 40 to 42) for tests of the original structures and excavation plan. An approximately 500 foot-wide section of the dam crest, forebay, and river channel downstream to RM 1.04 were included for tests of the completed structures. The spillway crest, abutments, pier and gates, chute walls, outlet conduits downstream from the valves, and fishway entrances were made of acrylic plastic. Formica was used for the chute floor and stilling basin. Steel pipes with flow controlled by gate valves were used to simulate the powerhouse penstocks. The spillway crest, designed for a head of 45.402 feet, was not changed during the studies but other elements were revised.

Plan A Spillway (Original Design)

Free Flow

46. The crest, abutments, and pier were tested individually. To eliminate the affects of the abutments, the crest and the crest with pier were isolated between false upstream walls for tests with free flow (photograph 6). Coefficients for the crest, pier, and abutments were obtained from the spillway discharge equation:

$$Q = C\left[L - 2(NK_p + K_a)\, H_e\right] H_e^{3/2}$$

in which

Q = discharge in cfs

C = crest discharge coefficient

L = net length of crest in feet

N = number of piers

K_p = pier coefficient

K_a = abutment coefficient

H_e = total energy head on crest in feet

47. For each test condition the equation of the best fitting straight line through the discharge data on a logarithmic plot was combined with the basic spillway discharge equation, and the following coefficient-head relationships were obtained:

$$C = 2.0434\ H_e^{0.1704},$$

$$K_a = 61.0\ H_e^{-1.0} - 72.918\ H_e^{-1.0582},$$

$$K_p = 47.675\ H_e^{-1.0} - 46.246\ H_e^{-0.9926}$$

Curves of the above relationships and corresponding curves from the Corps of Engineers Hydraulic Design Criteria (HDC) are shown on plate 43. The coefficients were slightly lower than the HDC values. The free flow discharge equation for the 100-foot-wide spillway was:

$$Q = 247\ H_e^{1.611}$$

which is shown in the rating curve on plate 44. The measured free-flow discharge at pool elevation 1600.0 was 157,200 cfs. The computed discharge based on HDC coefficients was 150,000 cfs at pool elevation 1600.6. In the belief that the 22-foot-wide pier would increase the coefficient, a conservative value of 0.03 for the pier contraction coefficient was assumed for design. The model data did not support this assumption.

48. Water surface profiles during maximum flow at pool elevation 1600.0 along the right abutment and right pier face and the pressure profile along the center of the right bay, measured at piezometers on plate 45, are shown on plate 46. Flow did not impinge on the gate trunnions. Pressures on the pier and abutments (table B) were lower than desired near the downstream ends of the circular noses and on the adjacent crest sections (piezometers A7 through A10; P7 through P10; and C4, C5, C28 and C29). The lowest pressure (-25 feet at piezometer A8) occurred with the maximum flow through two bays. The pressure at the adjacent crest piezometer (C4) was -22 feet, and the pressure at the corresponding point on the pier (piezometer P8) was -15 feet. With maximum flow through one bay, minimum pressures on the abutments

were 7 feet higher and pressures on the pier were approximately equal to those on the abutments. The effects of pool elevation on pressures at piezometers A8 and C4 are shown on plate 47.

Gated Flow

49. Discharge rating curves for gate-controlled flows over the spillway are shown on plate 48. Control of flow in the model shifted from the gates to the crest when the gate opening exceeded approximately 40 feet. Water surface profiles along the right abutment and right pier face and the pressure profile along the center of the right bay are shown for 5- and 30-foot gate openings at pool elevation 1600.0 on plates 49 and 50, respectively. Pressures on the crest, pier, and abutments were satisfactory for these gate openings (minimum pressure -4 feet, table C).

Conduit Outlets and Chute - Plan A Spillway

Plan A

50. As shown on plates 42 and 51, three outlet conduits located directly underneath the spillway discharge onto the spillway chute at station 47+09.24. The conduit invert profiles followed the lower nappe of the jet trajectory for a velocity equal to 1.17 times the average velocity developed at a head of 250 feet. The center conduit followed the centerline of the spillway and was 11 feet wide through its length. The two outside conduits converged from underneath the abutments to the edges of the spillway chute, and the outlets flared from 11.0 feet at station 47+65.00 to 16.08 feet at station 47+09.24. The tops of the outlets were flush (without overhang) with the chute flow. Piezometers were installed in the conduit outlets (plate 52) and along the chute (plate 53).

51. Water surface profiles in the spillway chute for combinations of spillway and conduit discharges are shown on plates 54 and 55. For spillway discharges greater than 20,000 cfs, flow across and into the conduit outlets caused heavy spray and standing waves that created additional spray at the walls in the lower end of the chute. A spillway flow of 157,200 cfs overtopped the chute walls near the abutments and the stilling basin (stations 49+75 to 49+00 and 43+60 to 44+30), and a 60-foot-high rooster tail formed downstream from the pier. The rooster tail was unstable, moved from side to side, and sometimes fell outside the spillway chute. Pressures in the chute and conduit outlets were satisfactory. The maximum impact of water in the outlets was 73 feet on the floor of the center conduit (spillway flow 157,200 cfs with no flow through conduits).

Chute Plans A-1 to A-6

52. A pier extension that protruded around and 10 feet beyond the center outlet (Plan A-1) and 50 feet beyond the center outlet (Plan A-2) eliminated the rooster tail and impact spray at that outlet. Flow conditions at the side outlets were the same as those with the original design. A tapered pier extension 80 feet long (Plan A-3) and the same extension with an eyebrow above the outlets (Plan A-4, plate 56) did not provide satisfactory flow conditions.

53. Isolating all three outlets from spillway flow by moving the side outlets outside the upper training walls and use of a long pier extension were investigated in Plans A-5 and A-6 (plate 57). With large flows through the spillway, two deep, narrow jets of water left the constricted chute section at the outlets and expanded rapidly on the curved chute floor. A rooster tail formed below the pier extension, and standing waves originating at the ends of the upper training walls overtopped the lower walls. Conditions below the outlets were improved, but flow distribution across the lower chute and into the stilling basin was not satisfactory.

Plan A

54. The Plan A stilling basin--80 feet wide and 320 feet long, with floor at elevation 919.0 (plates 42 and 58)--was the longest basin that could be constructed without redesigning the cofferdam and temporary facilities for fish passage. Owing to the short distance between the cofferdam and the stilling basin, a 45-degree 43-foot-high end sill was used instead of a conventional low end sill and runout slope to the river channel downstream. The stilling basin was designed to provide good energy dissipation for 40,000 cfs with an additional 5,000 cfs through the power units. Sweepout of the hydraulic jump occurred with releases considerably greater than 45,000 cfs standard project flood (SPF) but was acceptable because the basin exit was several hundred feet downstream from the toe of the dam where erosion of the riverbed would not endanger the dam.

55. The minimum tailwater for a stilling basin is defined as the minimum tailwater elevation at which a hydraulic jump occurs in the basin for a given discharge. The curve on plate 59 indicates that the Plan A basin was satisfactory for the design discharge of 40,000 cfs and a tailwater of 45,000 cfs (photograph 7). Flow conditions downstream from the basin were not satisfactory. Critical flow with localized maximum velocities of 18 fps and waves 8 feet high occurred in the exit channel during a spillway discharge of 40,000 cfs. The high plume of water that existed during sweepout at 90,000 cfs (photograph 7) would have severely eroded the adjacent river channel.

Plans A-1 to A-4

56. Stilling basin Plans A-1 to A-2 were constructed with sloping end sills 12 and 20 feet high, respectively (plate 58). Vertical end sills 20 and 43 feet high were tested in Plans A-3 and A-4. The

performance of stilling basins A and A-4 (sloping and vertical end sills 43 feet high, respectively) was similar for discharges below 45,000 cfs. Basin capacity was about 46,000 cfs with the sloping sill and 96,000 cfs with the vertical sill. The data on plate 59 indicates that the capacity for energy dissipation within the basin varied directly with the height of the end sill. With a riverflow of 45,000 cfs, there was no significant difference in velocities downstream from the basins with sloping or vertical end sills 20 feet high (plate 60). Maximum velocities 5 feet above the bottom were 7 fps with an end sill 12 feet high (Plan A-1). Although none of the basins were completely satisfactory, the best results were obtained with the 20-foot-high vertical end sill. A wider basin with less energy per foot of width was indicated.

Plan C Spillway, Plan D Chute, Plan B-2 Stilling Basin (Final Design)

Description

57. The studies of the Plan A structures indicated a need to increase pressures on the abutments and pier, to realign the two outside conduit outlets and the lower portion of the chute, and to increase the width of the stilling basin. In a series of developmental studies, the abutments and pier noses were fitted to an elliptical curve having semi-minor and semi-major axes of 5.0 and 15.0 feet, respectively; the outlet of the center conduit was protected by a divider wall that extended downstream from the pier; the side outlets were placed outside the upper chute walls; the lower portion of the chute was widened; and the stilling basin was widened from 80.0 to 114.0 feet, shortened from 320.0 to 280.53 feet, and raised from elevation 919.0 to 931.0. The developmental studies also examined tapered extensions of the center piers, various lengths of chute walls at the conduit outlets, various heights of stilling basin walls, and baffles in the stilling basin. The pier extensions were inadequate for improving flow in the lower chute, and the baffles caused no significant improvement in performance of the stilling basin.

58. A layout of the revised model structures, including an access road fill along the right bank, is shown on plate 61. Details of the Plan C crest, pier, and abutments are shown on plate 3, and details of the Plan D spillway chute and Plan B-2 stilling basin are shown on plates 2 and 62, respectively. The locations of piezometers in the spillway crest, pier, and abutments are shown on plate 63. The computed tailwater curves were revised to reflect the effect of the access road fill on water-surface elevations at North Fork Clearwater RM 1.10 (plate 64).

Plan C Spillway

59. Changing the curves of the abutments and pier nose from circular to elliptical increased the discharge capacity about 4 percent when free flow was passed over the model spillway. The discharge equation was $Q = 111\ H_e^{1.642}$ for free flow in a single bay. Gate rating curves for operation of one bay with gate openings between 3 and 35 feet and more-detailed ratings for 3- and 5-foot openings of both gates are shown on plate 65. Flow conditions adjacent to the abutments and pier are shown in photographs 8 and 9.

60. Pressures on the crest, pier, and abutments were satisfactory for free and gate-controlled flows at pool elevation 1600.0. The lowest pressures for free flow through both bays were -12 feet on the crest (piezometer 5), -3 feet at piezometer 27 in the pier, and -10 feet at a matching piezometer in the right abutment (table D). The lowest pressure for gated flow was -6 feet at crest piezometer 32. Water surface and pressure profiles for one- and two-bay operations are shown on plates 66 to 68, respectively.

Plan D Chute

61. The Plan D chute structure had an 8-foot-high by 22-foot-wide pier extension wall to prevent spillway flow from impinging in the center conduit outlet (plate 62). The wall extending from the spillway pier to the center conduit outlet, was expected to be effective

for spillway flows to 40,000 cfs and the water surface profiles on plate 69 indicate that the 8-foot wall was adequate. The pier extension wall was slightly submerged, and a thin sheet of water impinged in the outlet during a spillway discharge of 90,000 cfs. At a flow of 157,200 cfs a rooster rail formed over the partly submerged pier extension wall, flow impinged in the center outlet, and short portions of the upper chute side walls were overtopped. Spray in the lower chute was suppressed when an additional 41,000 cfs was passed through the outlets (plate 70). Except for the rooster tail and overtopping of the upper chute walls at 157,200 cfs, the Plan D chute was satisfactory.

Plan D-1 Chute

62. The downstream end of the center outlet was moved upstream to provide a thicker section for structural reasons as shown on plate 71 (compare with plate 62). Profiles of flow in the chute were the same as those on plates 69 and 70. The shorter roof overhang of Plan D-1 was less satisfactory than Plan D. Flow over the spillway impinged farther upstream on the conduit floor, and there was more spray at a spillway flow of 90,000 cfs. No increase in spray occurred at flows of 120,000 cfs and greater. Plan D was selected for the prototype.

Plan B-2 Stilling Basin

63. The minimum tailwater required to dissipate the energy of spillway flow in the stilling basin is shown on plate 72. The capacity of the basin with average or minimum tailwater at RM 1.10 was 50,000 cfs (plate 64). With lower discharges, tailwater elevations were controlled by topography downstream and tailwater at the stilling basin was above the minimum required for energy dissipation. Flow conditions in the stilling basin are shown in photograph 10. The basin was adequate for design conditions with a spillway flow of 40,000 cfs and tailwater resulting from a river discharge of 45,000 cfs (top picture).

The toe of the hydraulic jump remained at the PT of the spillway bucket during spillway and river discharges of 45,000 and 50,000 cfs, respectively (center picture). With spillway and river discharges of 85,000 and 90,000 cfs, respectively, most of the energy was dissipated in the exit channel (bottom picture). Six 10-foot-high baffle piers located either 90.0 or 67.5 feet upstream from the end sill did not increase basin capacity.

Dynamic Loads on Training Walls and End Sill

64. Water surface profiles and dynamic forces on the training walls and end sill of the Plan B-2 stilling basin were determined for use in structural design. The finite method of analysis was applied to the data to calculate the prestressing needed to stabilize the walls and end sill against the total dynamic loads in the prototype. Flush-mounted 1/2-inch-diameter 25 psia pressure cells were placed in the right wall as shown on plate 73, and pressures were measured for two-bay spillway flows of 20,000 cfs to 150,000 cfs at pool elevation 1600.0.

65. The normal range of water surface profiles measured in the stilling basin for spillway discharges between 10,000 and 90,000 cfs and the average backwater effect from Clearwater River are shown on plate 74. Excessively large pressure fluctuations occurred on the stilling basin walls (maximum -69* to 146 feet, cell 3) when the discharge exceeded the hydraulic jump capacity of the basin (table E). With hydraulic jump action in the basin, the maximum fluctuation was from -21 to 88 feet at 50,000 cfs.

* Pressure lower than -34 feet cannot occur in the prototype (see paragraph 7).

66. Pressures on the end sill and on the left wall at pressure cell 5 were measured with quick-acting piezometers and water manometers during spillway flows of 40,000 to 150,000 cfs. The locations of the piezometers and the pressure data are shown in table F. Pressures along the top of the end sill were in the range of cavitation when spillway flows exceeded the hydraulic jump capacity of the stilling basin.

Stilling Basin Self-Cleaning

67. After 3 years of project operation, the prototype stilling basin floor was found to have extensive damage apparently caused in part by debris washed into the basin during periods of nonuniform spill. Cleaning of the debris from the basin with flow was examined in the model with the existing end sill and with 2V-on-1H and 1V-on-1H sloping end sills. The tests were made with the best flow conditions for self-cleaning--spillway flow, uniform spill, and maximum pool (elevation 1600). The 1V-on-1H sloping sill was only slightly better than the other two, and with it the basin required a spill of 40,000 cfs to sweep out most of the debris. With the other two sills, a spill of 45,000 cfs (SPF) was required. Complete cleaning occurred only with higher sweepout flows; therefore, self-cleaning was not practical.

Stilling Basin Debris Control

68. Soon after erosion damage in the prototype basin was repaired, debris was again found inside. The model showed that powerhouse flows as high as 25,000 cfs did not move the 5/8- to 10-inch-diameter gravels and cobbles near the basin. However, spillway flow created eddy action at the edges of the outflow from the basin and moved this material into the runout excavation along the ends of the basin wall. The roller beneath the flow separating from the end sill carried the material to the upstream edge of the sill. Occasionally the highly turbulent flow

lifted from the edge of the sill, and the bottom roller swept the material into the basin. With time, sizeable amounts of debris accumulated in the basin. The bottom roller extended one-third to one-half the distance up the runout slope. Material on the slope beyond the roller was swept into the channel downstream. These observations were made with discharges of 10,000 to 40,000 cfs concurrent with a powerhouse flow of 5,000 cfs.

69. A rock trap was developed in the downstream end of the stilling basin that effectively collected incoming material. However, the trap was not considered a reasonable solution to the debris erosion problem. Material within the trap moved about and would cause erosion in that area.

70. Low walls that extended downstream from the basin walls were effective in stopping movement of material into the basin and two plans were developed. The first plan was a sheet pile wall 13 feet high above the channel bottom and 50 feet long extending downstream from each basin wall. A small amount of material accumulated behind the walls but did not overtop; flow conditions from the basin were not changed. A check of prototype site conditions showed the area was in rock and unsuited for sheet piles. The second plan was a low fill 4 feet high and 25 feet long extending from each wall (plate 75). The shorter, lower fills were as effective as the low walls in blocking material movement into the basin without changing outflow conditions. The extension fills were built in the prototype with tremie concrete.

Downstream Flow Conditions and Fish Passage

71. Flow conditions in the tailrace and downstream channel were investigated for various powerhouse operations and river discharges between 7,000 and 45,000 cfs (plates 76 to 78). Velocities downstream from the structures were too low to delay the upstream passage of fish or to block them from the stilling basin. However, a large clockwise

eddy which formed in front of the Plan A pumphouse intakes (plate 79) and the deflection of the 60 cfs fish attraction flows from two fishway entrances at powerhouse unit 1 and one entrance at unit 2 were undesirable. A pumphouse design (Plan C, photograph 11 and plate 80) was developed to eliminate the eddy and reduce excavation along the right bank. The two 2- by 6-foot submerged orifices at unit 1 were changed to a submerged weir that provided increased attraction flow along the face of the powerhouse. Overall flow conditions with the revised right bank (Plan C) are shown on plates 81 and 82.

72. A fish entrance through the right wall of the stilling basin connected to the powerhouse fish collection channel at unit 6. The entrance was 4 feet wide by 28 feet high and was located at station 43+03 (plate 62). Flow from the entrance was controlled by two telescoping 14-foot-high gate leaves. With 10,500 cfs through powerhouse units 1 to 3, a discharge of 120 cfs from the fishway entrance was adequate to attract fish from the stilling basin for spillway flows to 7,500 cfs (photograph 12). Conditions were equally satisfactory when the spillway was closed and 5,000 cfs was passed through the left conduit. A change in the location of the fishway entrance was not indicated.

Tailwater Elevations at Powerhouse

73. Average tailwater elevations at powerhouse units 3 and 6 were measured with 0, 5,000, 11,000, and 29,000 cfs through units 1 and 2, 1 to 3, and 1 to 6, respectively, and with discharges of 0 to 150,000 cfs over the spillway. The average water surface elevations at units 3 and 6 were the same.

74. The average tailwater curves on plate 83 show that under conditions with no powerhouse operation, with units 1 and 2, and with units 1 to 3 operating, respectively, the water surface elevations at the powerhouse rose with increasing discharge until sweepout flow from

the stilling basin began to repel tailwater in the narrow downstream channel. As more discharge passed over the spillway, the tailwater at the powerhouse was drawn down by high-velocity flow from the stilling basin. This effect was less apparent with six units operating. The maximum average tailwater of elevation 1004.6--which occurred with a powerhouse discharge of 29,000 cfs and a spillway discharge of 150,000 cfs--was below the tailrace deck at elevation 1005.0. The deck was occasionally overtopped by waves and fluctuating water levels during river discharges greater than 135,000 cfs when six powerhouse units were in operation. The fluctuating water levels were caused by slight, periodic shifting of the stilling basin outflow from one side of the channel center to the other. The fluctuation was greatest when the powerhouse was closed (+9.5 feet, river discharge 150,000 cfs) and least with maximum powerhouse flow (+3.2 feet, river discharge 190,000 cfs).

Variations in Maximum Probable Flood

75. As stated in paragraph 3, the Dworshak project was originally designed to pass a total discharge of 190,000 cfs at maximum pool elevation 1600.0. Of this flow, 150,000 cfs would go over the spillway and 40,000 cfs would pass through the regulating outlets. After further analysis of hydrometeorological data, the maximum probable inflow to the reservoir was increased from 280,000 to 411,000 cfs and the maximum regulated outflow was increased to 254,000 cfs at pool elevation 1610.5. This discharge was to be divided as follows: powerhouse 8,000 cfs, regulating outlets 41,000 cfs, and spillway 205,000 cfs. The increased flow had to be passed without interfering with the contract plan spillway bridge (photograph 13 and plate 3); otherwise, the bridge would have had to be revised.

Spillway Flows 205,000 and 208,000 cfs

76. A model discharge rating curve with the bridge in place and the gates in their maximum raised position is shown on plate 84. Free flow occurred with pool levels below elevation 1605; interference from the false camber on the upstream bottom edge of the bridge increased from pool elevation 1605 to 1609; and orifice flow (photograph 13) existed for higher pools. The discharge-head relationships were similar for rising and falling pools in the transition between free flow and orifice flow. With the maximum estimated spillway discharge of 205,000 cfs, the pool was at elevation 1611.0, the upper nappe of the outflow was about 7 feet below the bottom of the raised gate (elevation 1595.0), the wave along the pier was 3 to 5 feet below the gate trunnions, and the wave on the abutments was 7 to 10 feet below the trunnions. Flow overtopped the spray walls of the upper chute for most of their length. Negative pressures indicative of cavitation in the prototype existed at five piezometers on the crest and at four piezometers on the right abutment (table G).

77. With the spillway bridge removed or modified to permit higher pools, a discharge of 208,000 cfs (total discharge 257,000 cfs) was passed at pool elevation 1610.4 with 1 foot of clearance under spillway gates in the maximum raised position. Removing the bridge did not affect minimum pressures on the crest and abutment (table G). The walls of the upper chute and portions of the lower chute walls were overtopped. Spray from the roostertail and from waves below the conduit outlets was excessive even in the model which did not fully simulate air entrainment. Flow swept out of the stilling basin, and a plume of water approximately 250 feet high filled the valley downstream (photograph 14). The sweeping action of the flow lowered tailwater to elevation 971 at the powerhouse and created a critical depth control about 1,200 feet downstream from the stilling basin. Varying the tailwater between the estimated maximum and minimum at RM 1.10 (plate 64) had no significant effect on the critical depth section or tailwater at the powerhouse.

Spillway Flow 181,000 CFS

78. An alternative method for routing the maximum possible flood through the reservoir was selected that reduced the spillway design discharge to 181,000 cfs. As predicted from the discharge rating on plate 84, a free flow of 181,000 cfs passed over the spillway at pool elevation 1604.9. Flow profiles in the spillway and upper chute are shown in photograph 15 and on plates 85 and 86. Flow did not impinge on the raised gates or the trunnions. The highest point of the nappe just touched the false cambers of the bridge (plate 3) at the pier (photograph 15). The spray walls of the upper chute were overtopped between stations 48+65 and 48+05 by wave action. The water surface was usually 3 to 6 feet below the maximum upper surface shown on plate 85. No pressure data were observed for this discharge.

79. Fluctuating flow conditions which existed in the lower chute with spillway discharge only are shown in photograph 16 and on plate 86. The bottom spray walls of the lower chute were occasionally overtopped as much as 10 feet. With flow through the side conduits, flow profiles in the lower chute were lower.

PART V: REGULATING CONDUITS

Design Considerations

80. Three regulating conduits discharged into the spillway chute (plate 2). As originally designed (Plan A), each conduit was 9.0 feet wide by 12.5 feet high upstream from an eccentric-trunnion tainter valve and 11.0 feet wide by 17.0 feet high downstream from the valve (plates 62 and 87). Later the conduit width downstream was increased to 12.0 feet (plate 2). Heads on the valves measured above the valve seat ranged from 95 feet at pool elevation 1445 to 250 feet at pool elevation 1600. Computed discharges at these heads were 8,040 and 13,330 cfs per outlet. To allow use of emergency gates in the regulating conduits during periods of spill, the emergency gate slot for the center conduit was placed in the spillway pier and slots for the other gates were placed in the abutments. In plan view the center conduit was normal to the upstream face of the dam. The Plan A right and left conduits converged from normal to the dam axis at an angle of 5°38'01" (plates 87 and 88). The angle was decreased to 1°25'09.3" in the final design (plates 2 and 99).

81. The conduits had an initial downward direction of 10 degrees to fit the flow trajectories tangent to the spillway chute and to provide a more economical design. Accepted criteria for design of hydraulic structures indicated that a 10-degree angle of skew was the maximum for satisfactory pressures with a conventional, simple, elliptical bellmouth curve. An entrance of minimum length in which positive pressures would exist with all flows was desired. The 3.5-foot-wide emergency gate slots had the downstream corners offset 0.3 foot with converging walls having a 50-foot radius of curvature to prevent flow impingement into the slots and resulting low pressures immediately downstream. Since the sudden expansion of the conduits at the eccentric-trunnion tainter valves exposed all sides of the flow jets to air, a 60-inch-diameter vent was provided in each valve shaft. In the final design prototype, vents were 72 inches in diameter (plate 2). Each conduit was to be lined with steel from the emergency gate slots to the regulating valve.

82. Regulating valves of the eccentric-trunnion type were selected because they have a relatively simple sealing system that seals positively at all valve positions except when the trunnions are rotated downstream to raise or lower the valve, they permit aeration of all sides of the jet to reduce cavitation tendencies and friction is not a problem. A schematic drawing of the valve is shown on plate 87. The valves are sealed by moving them upstream against rubber compression seals with an eccentric-trunnion shaft that is rotated by a pivoted hydraulic cylinder and lever arm. The valves are moved off of the seals before being moved vertically. The valve seals are essentially like those at Lookout Point Dam but are larger due to the higher head at Dworshak and greater valve travel required for retraction and sealing. Since test data for this type of seal were not available, tests of a short length of prototype rubber seal, 60- to 70-durometer hardness, were made to determine the pressures it would withstand without blowby when compressed at varied amounts (paragraphs 101 through 106).

Conduit Intake

Model Description

83. A portion of the forebay and upstream face of the spillway, the right conduit, and a segment of the spillway chute were reproduced in a 1:20-scale model (plate 87). The intakes were cast as single plastic units of exceptional accuracy and were reinforced with ribs and flanges to prevent distortion. The tainter valve, valve well, and conduit were fabricated of clear acrylic plastic. Air was supplied to the model through a simulated 20-inch-diameter vent in the emergency gate slot cover, a 60-inch-diameter vent in the valve shaft, and two 15-inch-diameter vents that supplied a 12- by 12-inch aerator located in the conduit floor just downstream from the valve.

Plan A (Original Design)

84. Details of the original (Plan A) design for the right conduit entrance, having simple elliptical curves, and of the conduit invert from elevation 1350.0 to 1335.43 with the bottom air vent are shown on plates 88 and 89, respectively. Flow conditions in the conduit with a pool elevation of 1600 are shown in photographs 17 and 18 for valve openings of 2, 4, 8, and 12.5 feet. At valve openings of 2 and 4 feet, spray of increasing intensity occurred on the conduit roof. Spray and the jet impinged intermittently on the roof at the 8-foot valve opening and almost continuously at the 12.5-foot opening. Some of the spray resulted from impingement of the expanding jet on the conduit walls as the jet left the narrower valve section. The two 15-inch-diameter side vents served their purpose in admitting air under the jet at valve openings of 2 and 12.5 feet when the emergency gate slot vent was open or closed. The jet impinged on the aerator slot with intermediate openings, and water flowed upward through the vent pipes when the valve was opened 8 feet. With the valve wide open, discharges for pool elevations of 1445, 1520, and 1600 were 8,130, 11,160, and 13,900 cfs, respectively. The latter discharge was about 4.3 percent greater than the computed prototype flow.

85. Pressures at the piezometer locations shown on plate 90 are listed in table H. With full valve opening, pressures in the top left corner of the right conduit entrance were in the range of cavitation. Negative pressures that occurred in the area of jet expansion downstream from the valve (piezometers 41 to 46) were not critical. Minor negative pressures downstream from the valve housing (piezometers 67 to 79) indicated that design of the conduit invert for the jet trajectory at maximum discharge was satisfactory. Pressures at piezometers 80 to 86 showed a tendency for flow separation caused by the lack of tangency between the conduit invert and the spillway chute. Owing to the oblique alignment of the conduit, only the left edge of the conduit floor was tangent to the spillway surface. After this test, the width of prototype conduits was increased from 11 to 12 feet downstream from the valves; this change was not reproduced in the model.

Plans B and C

86. Details of the Plan B right conduit entrance are shown on plate 91. The bottom bellmouth curve was extended upstream beyond the face of the dam, and a bulkhead seat was recessed into the curve. The bellmouth was revised to compound elliptical curves. The conduit invert and aerator downstream from the valve lip were lowered 0.5 foot to reduce impact of flow into the aerator at partial valve openings (Plan B invert, plate 89). Piezometer locations in the Plan B right conduit entrance and conduit are shown on plate 92. Pressures at selected piezometers (table I) indicated the possibility of cavitation in the bottom left corner of the intake (piezometers 80B and 81B). Modifying the corbel at the bottom of the intake (plate 93) had no significant affect on pressures in the bellmouth. Flow impact into the revised floor aerator at partial valve openings was not reduced. Since pressures on the invert were satisfactory when the valve was wide open, the floor aerator was eliminated. The 1.5-foot offsets in the side walls and 1.4-foot drop in the invert at the valve should provide ample area for aeration of the jet; however, the aerator and Plan B invert were retained in the model for the remainder of the studies.

87. The Plan C right conduit entrance (plates 94 and 95) retained the compound curves of Plan B, but the horizontal skew was eliminated by extending the bellmouth beyond the face of the dam. Minimum pressures of -21 feet at piezometer 26C and -23 feet at piezometers 32C and 49C occurred in the Plan C bellmouth (table J).

Plan D

88. Both the vertical and horizontal skew were eliminated in the Plan D right conduit entrance (plates 96 and 97), and the entrance face was normal to the conduit centerline. The minimum pressure of -13 feet at piezometer 25D in the top left corner (table K) was considered acceptable. However, the higher pressures were obtained by

means of an expensive corbel on the upstream face of the dam. Pressures in the conduit downstream from the valve were satisfactory and approximately equal to those with the Plan A conduit (table H).

89. Pressure fluctuations and instantaneous pressures were investigated by means of a 1/2-inch-diameter pressure cell in the top edge of the right side of the bellmouth 0.5 foot downstream from piezometer 38D. The results verified the pressures obtained with piezometers and water manometers and indicated that -13 feet in the Plan D bellmouth was not indicative of possible cavitation. With intake Plans C and D, closing the valve only 0.2 foot from the full-open position created enough backpressure to raise the minimum pressure to zero. Based on this evidence, the Plan D intake was considered satisfactory for use in the prototype.

90. Discharge ratings of the tainter valve with the Plan D bellmouth for pool elevations 1445, 1550, and 1600 and with the valve fully open at pool elevations 1445 to 1600 are shown on plate 98. Maximum capacities of the conduit at pool elevations 1445 and 1600 were 7,910 and 13,750 cfs, respectively. Predicted discharges were 8,040 and 13,330 cfs.

Plan E

91. Although the Plan D bellmouth was the tentative final conduit entrance design and also the design modified for use in the regulating conduits at Libby Dam, additional tests were made to develop a short, skewed bellmouth entrance flush with the face of the dam that would have positive minimum pressures. Test results with bellmouth entrances Plans C and D had indicated that positive control of flow should be at the throat. In the Plan E right conduit entrance, the top and sides were simple elliptical curves that became tangent to convergent straight sections that ended at the emergency gate slots (plate 99). The top and side curves became tangent at the approximate

point where zero pressures occurred on the curves of Plan A. The throat area was not enlarged to compensate for the additional contraction because discharge in the Plan D conduit was slightly greater than required. Due to the realignment of the conduit exits in the spillway chute, the horizontal angle of convergence of the side conduits was reduced to 1°25'09.3".

92. Flow conditions in the Plan E right conduit entrance were similar to those shown in photographs 17 and 18. All pressures in the bellmouth at the piezometers shown on plate 100 were positive at the full valve opening (table L). Minimum pressures were 15 feet of water at piezometer 10 in the lower left corner and 21 feet at piezometer 21 in the upper right corner. Bulkhead guides on the upstream face of the dam (plate 101) had no affect on pressures in the bellmouth. A positive flow control existed at the upstream edge of the emergency gate slots. Free surface flow occurred downstream from the control between the bellmouth and valve. A large amount of air was drawn through the emergency gate slots to maintain these conditions. Without this air supply (which would always be available in the prototype), control shifted to the valve section and pressures dropped to 2 feet at piezometer 10 and -12 feet at piezometer 21. With air supplied through the emergency gate slots, the upstream edges of the slots retained control of flow until the valve was closed 0.3 foot with pool elevations 1600 and 1550 and 0.4 foot with pool elevation 1445. When the throttled valve was opened beyond these openings, control of discharge immediately shifted to the edge of the slot without causing unstable flow conditions.

93. Flow impinged intermittently on the downstream edges of the emergency gate slots. The maximum impact pressure was 73 feet at piezometer 52 on the side curve downstream from the slot. No negative pressures or high impact pressures were measured in the slots, which contained only 1 to 4 feet of water. Pressures were as low as -11 feet (piezometer 84) just beneath the water surface on the side walls near

the valve where the pressure gradeline dropped toward the center of the free jet emitted from the valve. These negative pressures are not considered critical, and they will occur on a steel liner in an area that can be dewatered for inspection. Increasing the offset would reduce impingement on the downstream corners of the emergency gate slots.

94. Uncontrolled discharges through the Plan E right conduit entrance were slightly less than those with Plans A and D but approximated the computed discharges. With minimum and maximum pools--elevations 1445 and 1600--conduit discharges were 7,710 and 13,270 cfs, respectively (plate 102). Computed flows for these pools were 8,040 and 13,330 cfs. Ratings of controlled flow were the same as Plan D (plate 97), but the upper limit of valve control was at openings of 12.1 and 12.2 feet instead of 12.3 feet. The selective withdrawal structure of the powerhouse is only 3.2 feet from the right conduit intake and extends 22.5 feet upstream from the dam. Tests indicated that the structure would have no adverse effects on average pressures and maximum discharge in the right conduit.

Prototype Entrances

95. The prototype entrances to conduits 1 and 3 (plate 2) conform in most respects to the Plan E design (plate 99). The distance from the face of the dam to the upstream edges of the emergency gate slots is the same--14.50 feet--but the overall distance to the valves was reduced from 31.98 to 30.10 feet. Since flow control for fully open valves will occur at the upstream side of the emergency gate slots, discharges and pressures should be similar to those indicated by the model.

Aeration Deflectors

96. The conduits were designed to aerate the top, sides and bottom of the high-velocity open-channel flow downstream from the valves to relieve low pressures and cushion the boundaries against cavitation

damage. Prototype operation showed that the aeration was inadequate. After the first 2 years, the conduit walls and floors had extensive minor cavitation damage at minor discontinuities such as lift and pour joints. Also, major damage occurred at distinct discontinuities that were not part of the proposed design. Repairs and corrections were made.

97. To enhance aeration of the flow, deflectors similar to ones successfully developed by the Bureau of Reclamation for its projects and by the Corps of Engineers for Libby Dam 1/ were developed for Dworshak in the 1:20-scale conduit model, which was revised to as-built prototype conditions (plate 103). The deflectors were wedges 2.25 feet long and 0.125 foot high placed on the walls and floors of the conduits immediately upstream of the valves (plate 104). Air entrainment in the model was not reproduced to a known scale of the prototype but was a qualitative indication of the action. The effectiveness of the deflectors was evaluated by comparison of the aeration created both with and without their use.

98. Reexamination of flow conditions in the existing conduits in the model showed that heavy aeration occurred with all valve openings at maximum pool (elevation 1600) and with large openings and intermediate pools (photographs 19 to 21). With small valve openings and intermediate pools and with all openings with minimum pool (elevation 1445), aeration was much lighter (photographs 22 to 24). When the openings were small, flow expanded rapidly at the top corners of the opening and created sheets of flow that impinged on the side walls near the valve. The sheets of flow cut off some but not all of the access of air to the underside of the outflow. Pressure beneath the flow at the valve was approximately atmospheric, which indicated an

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1/ Dortch, Mark S. "Center Sluice Investigation, Libby Dam, Kootenai River, Montana, Hydraulic Model Investigation," Technical Report H-76-21 dated December 1976, U.S. Army Engineer Waterways Experiment Station.

adequate air supply (table M). Along the floor of the conduit downstream, the pressure was also approximately atmospheric except at piezometers 6, 7, and 9 (plate 103) when the opening was large and the pool maximum (table M). The lower negative pressures in that area (-13 feet minimum) indicated the possibility of cavitation with large discharges (table M).

99. With the deflectors, heavy aeration occurred with all valve openings and pool levels (photographs 19 to 24). Pressures on the conduit floor were increased with the minimum measured pressure of -7.2 feet occurring at piezometer 9 (table M). The sheets of flow created at the top corners of small valve openings were deflected farther downstream, and the access of air to the underside of the flow was increased.

100. In the conduit as originally built, control of the flow shifted from the valve section to the emergency gate slots when the opening was increased beyond 12.1 or 12.2 feet. With the deflectors, the control was at the valve section with all openings and the conduit sections upstream of the valve were backpressured at all openings. The constriction of the flow area at the valve by the deflectors reduced the maximum capacity of the conduit by 2.0 percent to 13,000 cfs.

PART VI: MISCELLANEOUS TESTS

Tainter Valve Seals

101. The eccentric-trunnion tainter valves move horizontally to close against rubber seals mounted on a rectangular frame within each conduit (plate 87). Details of the proposed (type 1) seals are shown on plate 105. When the valves are closed, the seals at Dworshak Dam must prevent leakage under a maximum head of 250 feet of water.

Sealing Tests

102. Tests of a 3-foot-long piece of prototype seal in a pressure tank (top picture in photograph 25) indicated that the seal must be compressed 5/16 inch by valve movement to prevent blowby at a head of 242 feet of water. More than 323 feet of head was required to cause blowby when the seal was compressed 7/16 inch. The bottom pictures in photograph 25 show the seal before and after it was compressed 3/8 inch under a head of 300 feet. The seal recess was almost eliminated, and the load was transmitted directly to the base plate. Little or no extrusion of the seal bulb into the gap between the simulated valve face and retainer bar occurred during a continuous 40-hour test under a head of 300 feet.

Compression Tests

103. The forces required to compress a 3-foot length of prototype seal mounted between retainer bars with ends unrestrained were determined in a concrete-testing machine at the North Pacific Division Materials Laboratory, Troutdale, Oregon. Compression and decompression forces were measured by a strain gage bonded to a steel shaft that moved the simulated face of an eccentric-trunnion tainter valve horizontally toward or away from the seal at a speed of 1-1/2 inches per minute.

104. Seven runs were made in the first series of tests. In the first run (plate 106), the type 1 seal was held at maximum compression for 7 minutes before pressure was released. In the last run (plate 107), the seal was held at maximum compression (0.539 inch) for 1 hour. Decompression loads were smaller than compression loads; and since the seal did not regain its initial shape between runs, differences between the two loadings became smaller as the tests progressed. Maximum compression forces per foot of seal increased from 320 pounds (seal compressed 1/8 inch) to 5,300 pounds when the seal was compressed 9/16 inch.

105. In the second series of tests, three runs were made with the type 1 seal and its two modifications (plate 105). Type 2 was formed by cementing a 1/2-inch-wide by 5/16-inch-thick rubber strip along the center of the seal recess. In type 3, a similar strip was cemented into each corner of the seal recess and a 1/16-inch-thick steel shim was placed under the enlarged base to increase the recess depth to 3/8 inch. The rubber strips had the same physical characteristics as the type 1 seal. The test assembly was taken apart and the rubber seal was relaxed for about 10 minutes between runs; seal recovery was about 91 percent in this length of time.

106. Force requirements for incremental amounts of seal compression generally decreased between successive runs with the same type of seal. Maximum compression forces of 5,300, 5,740, and 4,080 pounds per lineal foot were required to compress seal types 1 through 3 by 9/16 (0.5625) inch (plate 108). Maximum forces of 7,700 and 6,270 pounds per lineal foot were measured when seal types 2 and 3 were compressed 0.6250 inch.

Powerhouse Fishway Diffuser

Description

107. Flows from a fishway entrance at the right side of the stilling basin and from weir or orifice gates along the downstream face of the powerhouse lead fish into an 8-foot-wide collection channel that ends at a holding pool on the right bank. Attraction water at the entrance and transportation flow in the collection channel are supplied by pumps with intakes that face downstream adjacent to unit 1 of the powerhouse (see paragraph 71 and plate 80). The pumps discharge into a 9-foot-wide conduit from which individual 2.5- by 3.0-foot sluice gates supply six diffusion chambers in the floor of the collection channel. The system is designed to supply 60 cfs per diffuser with sluice gates fully opened and a difference of 2.5 feet between the energy grade line in the supply conduit and the water surface elevation in the collection channel. Owing to the limited space in which to dissipate velocities through the sluice gates, model studies were made to perfect the proposed design and to insure acceptable performance of the diffusers.

Plan A (Original Design)

108. Details of the Plan A (original design) diffusion chamber and the 1:10-scale model in which it was tested are shown on plate 109. With average operating conditions of 200-cfs supply conduit flow to the sluice gate and hydraulic grade line in the conduit 2.5 feet above water surface elevation 979 in the collection channel, a diffuser discharge of 60 cfs was obtained with a sluice gate opening of 2.28 feet (plate 110). The discharge varied less than 1 cfs from the desired 60 cfs when the diffuser was operated under a head of 2.5 feet with 120 cfs in the supply conduit with water surface elevation 985 in the collection channel or with 424 cfs in the supply conduit and water surface elevation 974 in the collection channel.

109. Flow distribution at elevation 963 in the Plan A diffusion chamber is indicated by the velocities shown on plate 111. The velocities average 0.5 fps over the gross diffuser area and varied from less than 0.3 fps to 1.1 fps. A small zone of very slow reversing flow existed near the left wall of the model diffusion chamber. Although the distribution and velocities were acceptable, it was believed that changing the floor slope and baffle locations might eliminate the zone of reversing flow and decrease velocities over the top of the floor slope.

Modifications Tested

110. Flow conditions and velocities were observed with the following modifications:

Plan B: The top of the sloping floor was raised 0.33 foot to decrease the flow area at the downstream end of the slope, and the baffle against the left wall was moved 0.33 foot from the wall.

Plan C: Same floor slope as in Plan B; the baffle was moved back to its original position and was not moved again.

Plan D: Top of floor slope as in Plans B and C; toe of floor slope raised 1 foot by means of a vertical step.

Plan D-1: The roof corner adjacent to bubbler beams was square, instead of having a 1-foot radius as in Plan A (plate 112).

Plan D-1a: The distance from the center of the sluice gate to the upstream wall of diffusion chamber was increased to 20 feet (4 feet in Plans A to D-1).

Plan E: Toe of Plan D floor slope extended to horizontal floor.

Plan E-1: Square roof corner as in Plan D-1; Plan E floor.

Plan E-1a: Plan E floor and Plan E-1 roof; upstream wall 20 feet from sluice gate.

Plan F: Same as Plans C and D except toe of floor slope is 0.5 foot above horizontal floor.

Plan G: Toe of Plan F floor slope extended to horizontal floor.

111. Increasing the chamber length had no significant effect on flow distribution. In general, the distribution of flow was slightly better with the square roof corner than with the rounded one. Of the two plans with the square roof, Plan D-1 was selected beause the average of velocities was lower and the zone of reversing flow was smaller. Velocities from the Plan D-1 diffuser are shown on plate 113.

Fish Hatchery Jet Header

Description

112. A new type of rearing pond developed by the U.S. Fish and Wildlife Service was to be used at the Dworshak fish hatchery. Two jet headers with seven nozzles each, mounted vertically, were to supply and circulate the water in each rearing pond. Details of a typical jet header are shown on plate 114. Calibration of the header was necessary for hydraulic design and operation of control facilities. Each header was designed to discharge 0.223 to 0.668 cfs (100 to 300 gpm) with submergences of 2 to 6 inches above the top nozzle.

Test Results

113. A full-scale jet header, installed in a 2.0-foot-wide by 7.3-foot-long flume (plate 115), was tested with 0.167 to 0.892 cfs (75 to 400 gpm) through 1- and 1-1/4-inch-diameter nozzles. Tailwater was 2 inches above the center of the top nozzle in all tests. Discharges and pressures (relative to tailwater) in the 8-inch supply pipe located 2 feet upstream from the reducing elbow and at the top of the header are shown on plate 116. Upon correction for the distance from the point of measurement to the pond water surface, these data can be used to measure prototype discharges. Observed pressures, head losses through the header computed from these pressures, and velocities measured 1/4 inch downstream from the nozzles are shown in table N. The flow distribution through 1-inch nozzles was uniform; the 1-1/4-inch nozzles discharged slightly more flow at the bottom of the header. The expanding jets, with highest velocities at the top edge of the nozzles, impinged against each other and oscillated horizontally. This should increase the width of the circulation flow path in the rearing ponds.

Fish Hatchery Aerator and Deaerator

Description

114. Both aerators and deaerators are required in the water reuse and treatment facilities for fish rearing ponds at Dworshak and other modern hatcheries. These devices fit into a manifold system having three sizes of header pipes with from 16 to 24 aerators or deaerators per header. The design discharge for both devices was 125 gpm per nozzle with header pressures of 5 to 15 psi (10 psi optimum).

Test Results

115. Full-scale pairs of aerators and deaerators (plates 117 and 118) were assembled from standard black iron and PVC plastic pipe and rated in the test stand shown on plate 119. To save time, the aerators were rated with a 12-inch header and the deaerators were rated with an 8-inch header. The position of aerators and deaerators along the respective headers was simulated by varying header discharge by each. Comparative air-demand velocities were measured for all but the 1-1/2-inch PVC aerator, which was deficient in discharge.

116. Aerator water discharge ratings and air-demand velocities are shown in table O. Comparative air discharges computed from the velocities are listed in table P. The 10-psi data indicate that the discharge of various sized aerators differed from 0 to 7 percent depending on location along the header. Black iron and plastic 2-inch aerators with 1-1/2-inch nozzles most nearly met the optimum condition of 125 gpm at a header pressure of 10 psi. The most efficient aerators for entraining air were the 1-1/2-inch black iron with 1-1/2-inch nozzle and 3/4-inch air pipe and the 2-inch plastic with 2-inch nozzle and 1-inch air pipe.

117. Deaerator discharge ratings (table Q) varied from 1 to 5 percent depending on location along the header (10-psi data). The optimum of 125 gpm at 10 psi was met by black iron and plastic 1-1/2-inch deaerators with 1-1/4-inch nozzles.

Selector Gate Relief Panels

Description

118. The powerhouse selective withdrawal structure on the upstream face of the dam has 90 pressure-relief panels per intake gate to protect the gates against water hammer or excessive differential

pressures. Each panel is a butterfly valve mounted on a torsion bar in a frame 1 foot 10 inches high and 4 feet long (plate 120). To verify and supplement design computations, torque on the panel shaft and discharge for various openings of a single panel were measured in the 1:5-scale model shown on plate 121. The torsion bar of the prototype panel was not reproduced; instead, both ends of the model panel were fixed to a continuous shaft for measurements of torque. Details of the apparatus used to measure torque are shown on plate 122.

Test Results

119. Torque and discharge were measured for panel openings of 10 to 45 degrees and head differentials of approximately 3 to 20 feet (plates 123 and 124). Additional data for panel openings of 50 to 90 degrees (also shown on plates 123 and 124) were requested by the Hydraulic Analysis Branch of the Waterways Experiment Station; however, the testing facility was not large enough to pass the discharge of the largest openings with the higher heads.

120. To check the continuity of data, measurements with a 40-degree opening were repeated and compared with previous measurements. The maximum differences were about 4 percent in torque and 3 percent in discharge. The hydraulic loading of the Dworshak structure would not open the panel beyond 45 to 47 degrees. With openings of approximately 47 to 80 degrees, hydraulic loading on the panel created negative or closing torque; the maximum occurred between 60 and 70 degrees, but the exact opening was not determined. With an 80-degree opening--particularly for head differentials less than 10 feet--loads on the panel were almost balanced, and the torque fluctuated with greater amplitude and frequency than with other openings. With a 90-degree opening, small opening torque occurred which was about one-half that of a 45-degree opening. Only a small pressure-relief benefit would be gained in opening the panel beyond 70 degrees. The increase in discharge with an increase in opening from 70 to 90 degrees was only 5 to 7 percent.

TABLE A

DISCHARGE RATING

Plan A Diversion Tunnel, Average Tailwater

Gage No.	Mile	Discharge in CFS															
		5,000		10,000		15,000		20,000		30,000		40,000		55,000		60,000	
		Water-Surface Elevations in Feet MSL															
		Obs	Corr[1]	Obs	Corr	Obs	Corr	Obs	Corr	Obs	Corr	Obs	Corr	Obs	Corr	Obs	Corr
5	.45	-	-	991.8	991.3	998.6	994.8	1003.8	1000.4	1014.6	1010.4	1025.5	1019.4	1042.9	1032.1	1050.4	1045.7
6	2.45	985.5	985.4	991.9	991.4	998.6	994.8	1003.9	1000.4	1014.7	1010.4	1025.5	1019.4	1042.9	1032.1	1050.5	1045.7
A	2.16	985.3	985.2	991.8	991.3	998.6	994.8	1003.8	1000.4	1014.6	1010.4	1025.5	1019.4	1042.9	1032.1	1050.3	1045.6
B	2.20	985.4	985.3	991.8	991.3	998.5	994.8	1003.8	1000.4	1014.6	1010.4	1025.4	1019.4	1042.9	1032.1	1050.4	1045.6
13	1.45	972.1	-	975.0	-	976.9	-	978.7	-	980.4	-	983.2	-	985.2	-	986.4	-
14	1.45	972.1	-	975.2	-	977.3	-	979.1	-	981.5	-	980.7	-	982.4	-	983.1	-
15	1.10	971.5	-	974.5	-	976.7	-	978.7	-	981.8	-	984.5	-	987.8	-	988.9	-
16	1.10	971.5	-	974.5	-	976.7	-	978.7	-	981.8	-	984.5	-	987.9	-	988.1	-

[1] Forebay water-surface elevations corrected for differences in tunnel roughness, model to prototype

NOTES: 1. Tunnel layout is shown on plate 8.

2. Gage locations are shown on plate 4.

3. Tailwater rating curves are shown on plate 5.

TABLE B

PRESSURES

PLAN A CREST, ABUTMENTS, AND PIER

Free Flow Over Spillway

Piezometer Number	Flow Through Right Bay						Flow Through Both Bays		
	Spillway Discharge in CFS								
	40,000			78,000			157,200		
	Pool Elevation in Feet MSL								
	1582.2			1600.0			1600.0		
	Crest	Abutment	Pier	Crest	Abutment	Pier	Crest	Abutment	Pier
	Head on Piezometer in Feet of Water								
1	30	33	33	50	46	45	47	42	50
2	27	37	36	30	51	49	24	48	53
3	11	22	21	1	26	23	7	19	31
4	3	26	25	-14	30	27	-22	23	34
5	2	9	9	-12	1	- 1	-17	- 7	7
6	7	10	9	0	- 1	- 2	- 2	-10	4
7	5	2	2	0	-11	-12	- 1	-18	- 7
8	3	0	0	- 1	-18	-16	- 1	-25	-15
9	2	4	5	0	- 6	- 6	0	-13	- 2
10	4	1	2	3	-13	-11	4	-17	- 7
11	3	7	8	4	4	5	5	2	6
12	7	7	8	11	0	2	11	- 1	3
13	25	5	5	25	2	3	19	2	4
14	22	5	5	22	1	1	17	0	2
15	17	3	4	15	0	1	11	- 1	2
16	15	3	4	12	- 1	0	8	0	0
17	12	2	3	8	- 1	0	5	2	0
18	9	2	3	4	- 1	0	2	0	- 1
19	5	3	3	0	2	1	- 1	1	1
20	3	4	-	- 2	3	-	- 2	4	-
21	2	2	2	- 2	2	2	- 2	2	0
22	3	3	3	1	4	4	0	5	1
23	2			2			2		
24	6			9			8		
25	37			50			51		
27	11			0			5		
28	2			-14			-12		
29	2			-10			- 8		
30	7			1			2		
31	5			1			1		
32	3			0			- 1		
33	2			0			- 1		
34	2			2			0		
35	3			4			1		
36	0			0			2		

NOTES: 1. Details of structures are shown on plate 41.

2. Piezometer locations are shown on plate 45.

PRESSURES

PLAN A CREST, ABUTMENTS, AND PIER

Pool Elev 1600, Gated Flow Through Both Bays

Piezometer Number	Crest		Abutment		Pier	
	Gate Opening in Feet					
	5	30	5	30	5	30
	Head on Piezometer in Feet of Water					
1	59	53	55	49	56	53
2	56	39	58	53	59	56
3	55	19	53	35	54	40
4	50	7	55	38	56	43
5	46	6	50	17	50	23
6	10	9	52	17	53	23
7	-2	3	49	8	49	11
8	-1	2	49	4	49	7
9	0	2	45	11	45	14
10	1	5	46	6	45	10
11	0	5	5	12	1	12
12	1	8	11	10	9	9
13	58	37	1	4	1	4
14	58	33	-1	5	-1	2
15	54	28	1	0	1	0
16	51	23	-1	2	0	-2
17	48	18	1	-2	1	-1
18	9	8	0	1	0	-3
19	-2	-1	1	0	1	-1
20	-1	-4	1	4	-	-
21	-1	-4	1	2	2	0
22	0	-1	1	4	1	1
23	0	0				
24	1	6				
25	59	55				
27	53	24				
28	50	9				
29	45	8				
30	8	8				
31	-2	1				
32	-1	-3				
33	0	-2				
34	0	-1				
35	1	1				
36	1	2				

NOTES: 1. Details of structures are shown on plate 41.

2. Piezometer locations are shown on plate 45.

3. Gate opening is the vertical distance in feet between gate lip and seal elevation on the spillway crest.

TABLE D

PRESSURES

PLAN C SPILLWAY, POOL ELEV 1600

Piezometer Number	Flow Through Right Bay			Flow Through Both Bays								
	Spillway Discharge in CFS											
	80,000			40,000			90,000			157,200		
	Crest	Abutment	Pier	Crest	Abutment	Pier	Crest	Abutment	Pier	Crest	Abutment	Pier
	Head on Piezometer in Feet of Water											
3	1			47			26			- 5		
4	- 5			42			21			-10		
5	- 8			35			16			-12		
6	- 2			13			10			- 4		
7	- 1			- 1			4			- 2		
8	- 2			0			2			- 2		
9	- 1			1			2			- 1		
10	2			2			4			4		
11	4	2	4	1	9	9	3	13	11	5	1	5
12	11	- 2	1	1	13	11	4	10	9	11	- 3	- 2
13	23	1	2	55	- 2	0	42	3	2	18	0	3
14	19	- 1	1	51	- 1	- 2	37	4	0	16	- 2	1
15	13	0	0	47	- 1	0	31	0	- 1	10	- 1	1
16	10	- 1		43	0	- 2	26	1	- 3	7	- 1	0
17	7	- 1	0	35	0	- 1	20	- 1	- 2	5	- 2	0
18	2	- 1	- 1	10	1	- 1	8	2	- 2	1	0	- 1
19	- 1	1	0	- 4	1	1	- 2	1	0	- 1	0	1
20	- 2	3	2	- 3	2	0	- 5	1	3	- 3	2	3
21	- 2	2	1	- 2	0	1	- 4	1	0	- 2	1	1
22	0	4	3	0	1	1	- 1	3	1	0	5	2
23	2	35	34	0	56	57	0	47	51	2	30	42
24	9	14	12	3	51	51	5	35	37	9	7	20
25	-	3	2	-	46	46	-	27	29	-	- 3	7
26	-	- 4	- 4	-	41	40	-	21	21	-	- 8	0
27	- 1	- 6	- 6	46	35	32	28	16	15	5	-10	- 3
28	- 7			41			21			- 2		
29	- 8			33			15			- 4		
30	- 1			9			7			1		
31	0			- 3			- 1			0		
32	- 3			- 5			- 6			- 3		
33	0			- 2			- 3			- 1		
34	1			- 1			- 1			0		
35	3			0			0			2		

NOTES: 1. Details of structures are shown on plate 62.

2. Piezometer locations are shown on plate 63.

3. Discharges of 40,000 and 90,000 cfs were controlled by spillway gates.

TABLE E

PRESSURES ALONG LEFT WALL OF PLAN B-2 STILLING BASIN

Pool Elev 1600, Two-Bay Spillway Flow, Plan D Chute

Spillway Flow in CFS	Location	Maximum Inst.	Maximum Mean	Maximum Range	Minimum Inst.	Minimum Mean	Minimum Range
		Pressures in Feet of Water					
20,000	2	65	51	20	33	46	17
	3	59	51	15	40	46	12
	4	51	47	6	39	47	9
	5	50	47	7	38	47	8
	6	22	16	11	4	8	8
	7	15	10	7	-2	8	14
	8	19	16	7	6	17	13
	9	18	16	5	8	13	10
40,000	2	78	45	8	0	38	51
	3	72	45	33	8	37	47
	4	74	53	30	25	47	29
	5	63	53	16	36	52	22
	6	26	3	26	-13	7	30
	7	36	19	25	2	14	21
	8	36	20	21	- 4	18	36
	9	37	25	15	7	21	18
50,000	2	88	33	84	-21	33	81
	3	84	43	58	8	32	28
	4	74	47	39	16	43	34
	5	67	53	24	4	47	48
	6	17	3	20	-11	0	15
	7	27	7	24	-15	2	25
	8	37	17	27	- 7	7	22
	9	41	23	27	4	13	22
60,000	2	97	12	123	-30	9	85
	3	68	18	67	-17	18	54
	4	69	25	61	-10	25	62
	5	62	32	47	- 5	31	50
	6	19	--	22	--	--	--
	7	15	--	23	--	--	--
	8	15	5	16	-15	- 2	21
	9	20	- 1	22	- 4	3	15

Spillway Flow in CFS	Location	Maximum Inst.	Maximum Mean	Maximum Range	Minimum Inst.	Minimum Mean	Minimum Range
		Pressures in Feet of Water					
70,000	2	99	10	106	-27	15	92
	3	83	25	90	-48	18	103
	4	63	18	72	-24	16	69
	5	77	33	60	-27	37	83
	6	15	--	15	--	--	--
	7	21	--	18	--	--	--
	8	36	--	32	--	--	--
	9	28	7	25	-13	5	31
90,000	2	94	5	98	-19	5	66
	3	106	13	112	-57	25	122
	4	88	8	93	-56	17	108
	5	93	38	73	-31	28	94
	6	--	--	--	--	--	--
	7	--	--	--	--	--	--
	8	33	--	27	--	--	--
	9	32	5	31	-12	7	23
120,000	2	116	12	129	-20	3	93
	3	125	28	130	-44	10	116
	4	127	19	136	-58	20	114
	5	121	45	124	-35	33	108
	6	12	--	16	--	--	--
	7	10	--	19	--	--	--
	8	42	--	44	--	--	--
	9	31	3	41	-22	3	33
150,000	2	135	7	137	-47	7	174
	3	146	15	158	-69	17	142
	4	103	17	126	-48	11	97
	5	156	40	159	-35	19	168
	6	21	--	24	--	--	--
	7	19	--	28	--	--	--
	8	49	- 1	62	-14	- 1	62
	9	41	0	48	-28	0	46

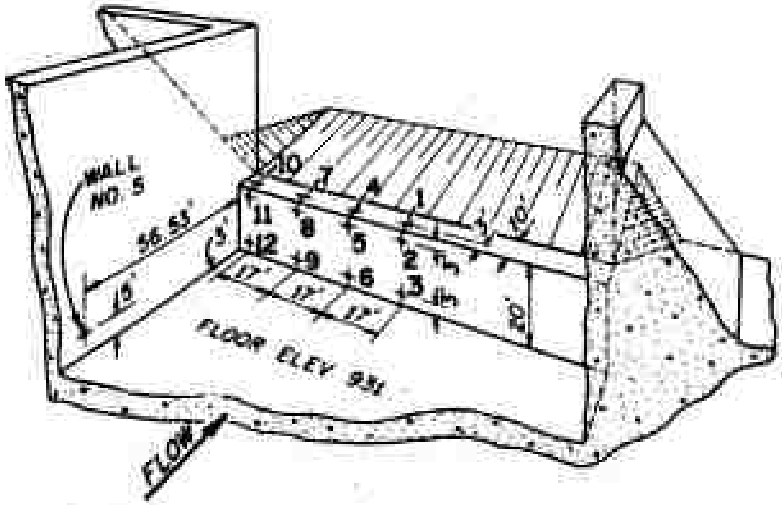
-- Pressure cell intake above water surface

NOTES: 1. Mean pressures and the range of pressures existed at time of instantaneous minimum or maximum observations.

2. Pressures were measured with 0.5-in., 25-psia, flush-mounted pressure cells at the locations shown on plate 73.

PRESSURES ON END SILL

Plan B-2 Stilling Basin



Piezometer Number	Spillway Discharge in CFS					
	40,000		90,000		150,000	
	Head on Piezometer in Feet of Water					
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1	32	40	-29	10	-41	-10
2	37	42	106	166	183	327
3	51	57	89	145	167	246
4	30	40	-22	11	-30	1
5	37	44	64	196	235	372
6	51	58	60	133	171	287
7	26	41	-15	27	-35	- 1
8	39	48	29	85	141	264
9	53	60	42	86	123	193
10	24	42	- 4	28	-35	- 2
11	39	48	34	75	109	153
12	53	61	52	106	124	230
Wall #5	47	53	6	42	13	51

NOTES: 1. Details of structures are shown on plate 62.

2. Pressures were measured by means of quick acting water-manometers.

TABLE G

PLAN C SPILLWAY WITH AND WITHOUT BRIDGE

Simulated Two-Bay Flow

Piezometer Number	With Bridge, Pool Elev 1611.0 Discharge 205,000 CFS		Without Bridge, Pool Elev 1610.4 Discharge 208,000 CFS	
	Crest	Abutment	Crest	Abutment
	Head on Piezometer in Feet of Water			
3	-23		-23	
4	-29		-28	
5	-30		-29	
6	-15		-14	
7	-11		-10	
11		- 7		- 7
12		-14		-13
13		- 7		- 6
14		-10		- 9
23		27		27
24		- 6		- 6
25		-19		-19
26		-27		-26
27		-28		-28

NOTES: 1. Details of structures are shown on plates 2 and 62.

2. Piezometer locations are shown on plate 63.

3. Pressures were the lowest that were indicated by means of water manometers. The pressures fluctuated 1 to 3 ft.

TABLE H

PRESSURES

PLAN A RIGHT CONDUIT, POOL ELEV 1600.0

Piezometer Number	Valve Opening in Feet: 2.0	4.0	8.0	12.5	
	Discharge in CFS: 1,750	3,380	6,680	13,900	
	Bulkhead Vent: Closed	Closed	Closed	Closed	Open
	Head on Piezometer in Feet of Water				
1	228	227	221	195	*
2	229	226	216	170	*
3	230	226	209	136	*
4	230	224	201	96	*
5	230	223	194	65	*
6	230	221	186	29	*
7	230	220	180	9	*
8	230	220	178	- 8	*
9	230	220	178	- 8	*
10	228	228	225	215	*
11	229	227	218	181	*
12	229	224	204	115	*
13	229	222	193	64	*
14	229	221	183	20	*
15	229	219	176	-13	*
16	229	219	173	-26	*
17	230	219	175	-20	*
18	229	219	176	-20	*
19	237	232	213	138	*
20	237	230	206	98	*
21	236	229	201	74	*
22	236	227	190	23	*
23	236	226	185	- 6	*
24	236	226	184	1	*
25	236	226	184	- 1	1
26	229	228	224	207	*
27	229	226	213	165	*
28	229	224	200	96	*
29	229	221	184	23	*
30	229	219	177	-10	*
31	229	219	174	-26	*
32	230	219	173	-33	-26
33	218	228	225	215	*
34	219	227	220	189	*
35	220	226	210	139	*
36	220	223	196	74	*
37	220	222	187	34	*
38	219	220	182	13	*
39	220	220	176	-10	- 4
40	240	219	152	0	1
41	-	-	7	-	-
42	-	-	1	-	-
43	-	-	3	-	-
44	-	-	58	-	-
45	-	-	11	-	-

Piezometer Number	Valve Opening in Feet: 2.0	4.0	8.0	12.5	
	Discharge in CFS: 1,750	3,380	6,680	13,900	
	Bulkhead Vent: Closed	Closed	Closed	Closed	Open
	Head on Piezometer in Feet of Water				
46	-	1	0	-	-
47	2	1	33∇	-	-
48	-	-	37	-	-
49	-	-	56	-	-
50	-	29	63	-	-
51	- 1	1	51∇	-	-
52	- 3	- 3	53∇	-	-
53	-	-	42	-	-
54	7	44	72∇	-	-
55	-	-	22	-	-
56	-	27	40	-	-
57	15	41	57	-	-
58	- 2	- 2	35	-10	- 8
59	-	-	21	-	-
60	19	27	39	-	-
61	-	-	11	-	-
62	-	13	19	-	-
63	12	17	24	-	-
64	-	7	9	-	-
65	9	11	13	-	-
66	- 2	9	6	5	- 3
67	0	0	- 4	- 3	- 4
68	1	2	- 3	- 7	- 6
69	1	2	- 1	- 8	- 4
70	1	2	0	- 7	- 8
71	1	2	- 1	- 7	- 8
72	2	2	0	- 6	- 5
73	1	2	- 1	- 6	- 6
74	1	2	1	- 4	- 5
75	2	2	2	- 2	- 3
76	2	3	3	1	0
77	2	3	3	3	2
78	2	3	3	4	3
79	2	3	3	3	3
80	- 2	- 2	- 3	- 2	- 3
81	- 5	- 7	- 7	- 8	- 9
82	- 4	- 6	- 6	- 6	- 7
83	- 3	- 4	- 4	- 4	- 5
84	1	- 3	- 3	- 3	0
85	0	0	0	0	- 1
86	1	2	3	3	6
87	-	-	-	8	-10

* No observation
\- Piezometer not in contact with flow
∇ Pressures varied ± 5 ft from mean; maximum value is shown

NOTES. 1. Details of conduit and piezometer locations are shown on plates 88 and 90.

2. The 60-in.-diam air vent was open for all tests.

3. Just after piezometer lines were flushed, nearly constant pressures of -7 to -10 ft existed at piezometers 41 to 65 when the valve was open 12.5 ft.

TABLE I

PRESSURES

PLAN B RIGHT CONDUIT, POOL ELEV 1600.0

Piezometer Number	Valve Opening in Feet			Piezometer Number	Valve Opening in Feet			Piezometer Number	Valve Opening in Feet		
	10.0	12.0	12.5		12.0	12.5			12.0	12.5	
	Discharge in CFS				Discharge in CFS				Discharge in CFS		
	8,970	12,250	13,810		12,250	13,810			12,250	13,810	
	Gate Slot				Gate Slot				Gate Slot		
	Closed	Closed	Open		Closed	Closed	Open		Closed	Closed	Open
	Head on Piezometer in Feet of Water				Head on Piezometer in Feet of Water				Head on Piezometer in Feet of Water		
1B	224	*	192	46B	52	2	-	152B	-10	-	-
2B	218	*	178	47B	53	2	2	53	-6	-	-
3B	234	*	216	48B	54	9	-	54	[illegible]	-	-
4B	235	*	218	49B	56	7	-	55	4	-	-
5B	184	*	126	50B	60	12	0	56	[illegible]	-	-
6B	159	*	61	51B	56	7	6	57	[illegible]	-	-
7B	147	*	29	52B	*	44	-	158B	[illegible]	-	-
8B	139	*	11	53B	49	15	1	59	[illegible]	-	-
9B	134	*	-1	54B	41	9	1	60	[illegible]	-	-
10B	132	*		55B	40	11	1	61	[illegible]	-10	-
11B	132	*	-3	56B	67	17	30	62	[illegible]	-	-
12B	203	*	165	57B	43	6	1	63	33	-	-
13B	153	*	46	58B	37	5	2	64	30	-9	-
14B	132	*	-3	59B	37	5	4	65	37	-	-
15B	133	*	-2	60B	48	-10	-8	166B	[illegible]	-10	-
16B	137	*	-4	61B	34	-6	1	167B	1	4	
17B	144	*	0	62B	31	-6	1	168B	-11	-1	-4
18B	132	*	-7	63B	32	-4	3	69	-11	-11	-11
19B	186	*	110	64B	27	-10	0	70	*	*	-10
20B	164	*	65	65B	26	-9	-2	71	*	*	-11
21B	146	*	11	66B	30	-5	1	72	*	*	[illegible]
22B	140		6	67B	45	-15	-13	73	*	*	[illegible]
23B	141	*	7	68B	25	-10	-5	74	*	*	[illegible]
24B	184	*	120	69B	27	-6	-3	75	*	*	[illegible]
25B	144	*	24	70B	26	-4	-1	76	*	*	-
26B	132	*	-9	71B	28	-9	-7	77	*	*	-1
27B	133	*	-3	72B	27	-5	-4	78	*	*	[illegible]
28B	134	*	-3	73B	27	-5	-3	79	*	*	[illegible]
29B	180	*	86	74B	23	-8	-6	80	*	*	[illegible]
30B	138	*	-13	75B	23	-7	-5	81	*	*	[illegible]
31B	139	*	-12	76B	26	0	3	82	*	*	[illegible]
32B	142	*	-6	77B	29	3	4	83	*	*	-
33B	137	*	-11	80B	33	*	-24	84	*	*	-1
34B	185	*	105	81B	32	*	-26	85	*	*	[illegible]
35B	162	*	52	41	-9	-	-	86	*	*	[illegible]
36B	137	*		42	-10	-	-				
37B	138	45	-10	43	-9	-	-				
38B	159	*	52	44	-10	-	-				
39B	144	*	20	45	-10	-	-				
40B	196	*	155	46	-10	-	-				
41B	176	*	103	47	-10	-	-				
42B	158	*	66	48	-9	-	-				
43B	141	*	23	49	-11	-	-				
44B	138	*	8	50	-9	-	-				
45B	140	*	23	51	-9	-	-				

* No observation
- Piezometer not in contact with flow

NOTES: 1. Details of conduit and piezometer locations are shown on plates 91 and 92.

2. The 60-in.-diam air vent was open for all tests.

3. Just after piezometer lines were flushed, nearly constant pressures of -7 to -10 ft existed at piezometers 41 to 65 when the valve was open 12.5 ft.

PRESSURES

PLAN C RIGHT CONDUIT ENTRANCE

Piezometer Number	Pool Elevation			Piezometer Number	Pool Elevation		
	1600	1600	1440		1600	1600	1440
	Valve Opening in Feet				Valve Opening in Feet		
	12.5	12.3	12.5		12.5	12.3	12.5
	Discharge in CFS				Discharge in CFS		
	13,820	13,225	7,800		13,820	13,225	7,800
	Head on Piezometer in Feet of Water				Head on Piezometer in Feet of Water		
1C	46	63	13	26C	-21	3	0
2C	23	41	6	27C	-18	6	2
3C	5	125	0	28C	-13	11	4
4C	3	121	0	29C	- 5	17	7
5C	60	*	17	30C	- 7	15	6
6C	35	53	8	31C	-18	5	2
7C	14	33	2	32C	-23	0	0
8C	59	*	17	33C	-19	4	1
9C	30	49	8	34C	-12	12	4
10C	13	33	2	35C	137	*	*
11C	- 1	20	- 1	36C	120	*	*
12C	- 4	15	- 1	37C	98	*	*
13C	-12	- 2	- 3	38C	70	*	25
14C	145	*	*	39C	44	60	17
15C	95	*	*	40C	26	45	10
16C	68	*	29	41C	12	32	6
17C	24	44	15	42C	43	60	11
18C	6	28	10	43C	20	40	5
19C	- 7	16	4	44C	5	25	0
20C	-10	14	3	45C	100	*	*
21C	-10	14	4	46C	- 1	20	6
22C	- 3	20	7	47C	-13	10	2
23C	100	*	*	48C	-17	6	1
24C	-10	13	4	49C	-23	1	0
25C	-19	4	1	50C	-17	7	2
				51C	-10	13	5

* No observation

NOTES:
1. Details of entrance are shown on plate 94.
2. Piezometer locations are shown on plate 95.
3. The 60-in.-diam air vent was open for all tests.

TABLE J

TABLE K

PRESSURES

PLAN D RIGHT CONDUIT ENTRANCE

Piezometer Number	Pool Elevation 1600	Pool Elevation 1600	Pool Elevation 1375*
Valve Opening in Feet	12.5	12.3	12.5
Discharge in CFS	13,710	13,280	2,937
	Head on Piezometer in Feet of Water		
1D	32	44	10
2D	8	22	9
3D	- 4	10	8
4D	5	18	9
5D	61	71	11
6D	28	36	10
7D	- 1	13	9
8D	4	18	10
9D	87	99	13
10D	46	58	10
11D	19	32	9
12D	151	156	21
13D	60	70	11
14D	24	34	10
15D	4	18	9
16D	- 1	13	9
17D	6	20	10
18D	9	24	10
19D	10	26	11
20D	36	48	10
21D	13	25	9
22D	- 3	11	8
23D	28	39	- 3
24D	1	14	- 3
25D	-13	1	- 4

Piezometer Number	Pool Elevation 1600	Pool Elevation 1600	Pool Elevation 1375*
Valve Opening in Feet	12.5	12.3	12.5
Discharge in CFS	13,710	13,280	2,937
	Head on Piezometer in Feet of Water		
26D	51	61	- 2
27D	14	26	- 3
28D	- 8	5	- 4
29D	-10	2	- 3
30D	76	88	- 1
31D	31	48	- 2
32D	7	20	- 3
33D	142	150	1
34D	57	65	- 2
35D	15	28	- 3
36D	- 7	6	- 3
37D	-13	0	- 3
38D	-10	4	- 2
39D	- 9	4	- 2
40D	- 6	4	- 1
41D	24	36	- 3
42D	1	14	- 3
43D	-13	1	- 3
44D	-10	4	- 3
45D	62	72	5
46D	31	43	4
47D	11	24	6

* Minimum pool for full flow in bellmouth

NOTES: 1. Details of entrance are shown on plate 96.

2. Piezometer locations are shown on plate 97.

3. The 60-in.-diam air vent was open for all tests.

TABLE L

TABLE L

PRESSURES

PLAN E RIGHT CONDUIT ENTRANCE

Pool Elev 1600, Valve Open 12.5 Feet,
Discharge 13,270 CFS, Bulkhead Slots Open

Bottom Corners		Top Corners		Between Bellmouth and Valve			
Piezometer Number	Pressure in Feet of Water	Piezometer Number	Pressure in Feet of Water	Piezometer Number	Pressure in Feet of Water	Piezometer Number	Pressure in Feet of Water
1	61	16	170	46	2	64	- 1
2	42	17	128	47	0	65	0
		18	106	48	1	66	3
3	75	19	93	49	5	67	-10
4	48	20	68	50	0	68	- 2
5	32	21	21				
6	129	22	193	51	1	69	3
7	61	23	149	52	73*	70	4
8	41	24	117	53	35	71	2
9	28	25	102	54	29	72	5
10	15	26	80	55	5	73	6
		27	48	56			
11	89					74	1
12	49	28	148	57	26	75	2
13	36	29	122	58	32	76	7
14	21			59	23	77	10
15	17	30	137	60	- 4	82	6
		31	112	61	5	83	- 7
		32	99	62	5	84	-11

* Piezometer was intermittently above water surface.

NOTE: Entrance details and piezometer locations are shown on plates 99 and 100.

TABLE

PRESSU

AS-BUILT C

With and Without Aer

Piezometer Number	Pool Elevation in F										
	1445						1550				
	Valve Opening in Feet						Valve Opening in Feet				
	1.0		8.0		12.5		1.0		8.0		12.5
	Aeration Deflectors						Aeration Deflectors				
	W/O	With	W/O	With	W/O	With	W/O	With	W/O	With	W/O
	Pressure in Feet of Water						Pressure in Feet of Water				
1R	-0.6	0	2.6	0.1	-2.5	0	-0.7	-0.4	-0.7	-0.9	-4.
1C	-0.5	0	2.3	0.3	-5.0	0	-0.5	-0.3	-1.4	-0.8	-5.
1L	-0.3	0.1	3.3	0.5	-3.2	0	-0.4	-0.4	-1.1	0	-4.
2R	0	-0.1	6.1	4.9	-2.1	0	-0.3	-0.4	6.9	5.7	-4.
2C	-0.2	0	18.4	13.7	-3.9	0	-0.2	-0.3	7.9	0.4	-5.
2L	-0.5	-0.6	19.9	1.1	-3.1	0	-0.8	-0.9	7.4	2.2	-4.
3R	1.3	0	24.0	2.0	-2.4	0.2	-0.5	-0.6	13.2	-2.6	-3.
3C	0.2	0.1	25.0	10.7	-3.8	0.2	-0.1	-0.2	38.2	6.2	-5.
3L	-0.4	0	15.2	6.0	-4.3	0.2	-0.8	-0.5	18.6	0.7	-5.
4	1.0	0.1	11.9	17.7	-3.9	0.2	4.8	-0.1	21.1	24.8	-4.
5	0.6	1.3	2.8	3.4	9.6	14.6	0.7	2.1	-0.2	2.4	4.
6	-0.9	-1.5	0.5	0.9	2.8	5.1	-2.9	-3.3	-4.0	-3.2	-6.
7	-1.2	-1.8	0	0.7	-0.7	2.8	-3.6	-3.1	0.3	-3.5	-9.
8	0.3	0.6	1.8	2.3	3.4	4.8	0.3	0.5	-0.9	0.3	-3.
9	-1.5	-2.0	0.6	1.2	-0.4	2.8	-3.2	-2.5	-5.0	-3.7	-8.
10	0.6	0.4	2.8	2.5	3.5	4.6	0.5	0.4	-0.6	0.3	-3.
11	-0.5	-1.0	1.2	1.2	1.4	3.0	-1.9	-1.3	-2.8	-1.5	-6.
12	-0.1	0.9	1.4	1.6	2.4	3.2	-0.5	-0.5	-0.4	0.1	-4.
13	2.1	2.2	4.1	4.1	5.1	5.6	2.4	2.3	3.6	3.8	0.
14	1.7	1.8	2.9	2.9	3.7	4.4	1.7	1.6	2.7	2.6	0.
15	0.8	1.2	2.6	2.5	3.7	3.9	1.1	1.1	2.6	2.6	1.
16	0	5.1	0.4	6.0	1.4	2.1	-0.2	0.1	0.3	0.8	-0.
17	0.3	0.1	1.7	1.1	2.8	2.3	0.3	-0.1	1.8	1.1	1.
18	0.6	0.4	2.3	2.1	4.1	3.6	0.8	0.6	2.6	2.3	3.

NOTE: Conduit details and piezometer locations shown on plates 2, 103,

TABLE M

1

TABLE M

PRESSURES

AS-BUILT CONDUIT

With and Without Aeration Deflectors

Pool Elevation in Feet in MSL														
1550					1600									
Valve Opening in Feet					Valve Opening in Feet									
1.0		8.0		12.5	1.0		3.0		8.0		12.0		12.5	
Aeration Deflectors					Aeration Deflectors									
W/O	With	W/O	With	W/O	W/O	With	W/O	With	W/C	With	W/O	With	W/O	With
Pressure in Feet of Water					Pressure in Feet of Water									
-0.7	-0.4	-0.7	-0.9	-4.4	-0.8	-0.5	-1.4	-0.7	-1.4	-2.5	-4.6	-2.1	-5.9	-4.4
-0.5	-0.3	-1.4	-0.8	-5.9	-0.6	-0.5	-1.2	-0.9	-4.1	-3.3	-5.1	-2.4	-6.6	-4.4
-0.4	-0.4	-1.1	0	-4.5	-0.5	-0.6	-1.2	-1.0	-2.7	-2.2	-3.4	-1.9	-6.3	-4.4
-0.3	-0.4	6.9	5.7	-4.1	-0.3	-0.6	-1.3	-1.1	3.4	1.4	-3.6	-1.9	-5.9	-4.6
-0.2	-0.3	7.9	0.4	-5.1	-0.5	-0.5	-1.1	-1.1	14.9	-2.3	-4.6	-2.0	-5.9	-4.6
-0.8	-0.9	7.4	2.2	-4.8	-0.8	-1.1	-2.1	-2.7	13.4	1.9	-3.9	-2.1	-6.3	-4.5
-0.5	-0.6	13.2	-2.6	-3.9	-0.6	-0.9	-1.8	-1.8	43.9	-5.8	-3.6	-2.0	-5.8	-4.0
-0.1	-0.2	38.2	6.2	-5.3	-0.3	-0.4	-0.6	-0.9	26.0	3.2	-3.0	-2.3	-6.0	-4.5
-0.8	-0.5	18.6	0.7	-5.1	-0.9	-0.8	-1.6	-1.5	24.4	-0.7	-3.5	-2.3	-6.1	-4.1
4.8	-0.1	21.1	24.8	-4.7	7.3	-0.2	7.5	-0.4	25.8	24.8	19.8	-1.4	-5.9	-4.6
0.7	2.1	-0.2	2.4	4.6	0.5	4.1	-0.4	2.4	-3.1	-0.2	11.1	13.9	-2.4	-3.6
-2.9	-3.3	-4.0	-3.2	-6.7	-4.0	-4.1	-6.2	-5.0	-9.0	-6.1	-11.8	-7.0	-11.6	-5.0
-3.6	-3.1	0.3	-3.5	-9.7	-4.7	-3.8	-7.2	-4.5	-9.0	-6.5	-12.0	-7.0	-13.0	-5.5
0.3	0.5	-0.9	0.3	-3.3	0.1	0.4	-0.5	0.3	-3.9	-2.5	-4.6	-0.7	-6.6	-3.2
-3.2	-2.5	-5.0	-3.7	-8.9	-3.1	-3.1	-5.7	-4.0	-8.9	-7.2	-10.4	-5.7	-12.4	-4.1
0.5	0.4	-0.6	0.3	-3.4	0.4	0.4	-0.1	0.1	-3.6	-2.7	-4.1	-1.3	-5.9	-1.9
-1.9	-1.3	-2.8	-1.5	-6.8	-0.8	-1.5	-2.6	-2.0	-6.3	-5.0	-8.2	-4.1	-8.6	-2.5
-0.5	-0.5	-0.4	0.1	-4.3	-0.5	-0.6	-1.0	-0.7	-4.3	-2.6	-5.3	-2.4	-5.8	-1.4
2.4	2.3	3.6	3.8	0.6	2.1	2.0	2.1	2.3	0.1	1.7	-0.7	6.6	-1.7	2.0
1.7	1.6	2.7	2.6	0.5	1.6	1.6	1.5	1.6	0.6	1.3	-0.2	0.8	-0.7	1.6
1.1	1.1	2.6	2.6	1.7	1.0	0.9	0.9	1.4	1.8	2.3	0.9	2.1	0.6	1.7
-0.2	0.1	0.3	0.8	-0.2	-0.2	0	-0.2	0.1	0.3	1.0	-0.6	0.1	-0.7	0.4
0.3	-0.1	1.8	1.1	1.4	0.3	-0.1	0.5	0	1.8	1.1	1.3	0.8	1.5	0.9
0.8	0.6	2.6	2.3	3.1	0.7	0.5	1.1	0.9	2.6	2.3	3.0	2.6	3.9	2.4

ions shown on plates 2, 103, 104.

TABLE N

DATA SUMMARY

Fish Hatchery Jet Headers

Nozzle Diameter (Inches)	Discharge		Pressure in Ft of Water Above Tailwater		Head Loss in Ft of Water From 8-in. Pipe to Tailwater
	CFS	GPM	8-in. Pipe	Top of Header	
1 1/4	0.167	75	0.21	0.18	0.21
	0.323	144	0.77	0.60	0.78
	0.413	185	1.23	0.99	1.25
	0.543	243	2.12	1.69	2.16
	0.647	290	2.99	2.38	3.04
	0.768	344	4.26	3.38	4.33
	0.892	400	5.75	4.58	5.84
1	0.167	75	0.42	0.39	0.42
	0.343	153	1.67	1.50	1.68
	0.413	185	2.38	2.14	2.40
	0.530	237	3.94	3.52	3.97
	0.647	290	5.77	5.16	5.82
	0.765	343	8.17	7.29	8.24
	0.892	400	11.07	9.88	11.16

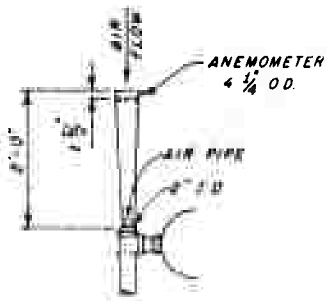
Discharge in CFS (or GPM)	Nozzle No. (Top to Bottom)	Velocity in CFS	
		1 1/4-in. Nozzle	1-in. Nozzle
0.167	1	3.2	4.5
	2	3.2	4.5
(75)	3	3.2	4.5
	4	3.3	4.5
	5	3.4	4.4
	6	3.6	4.5
	7	3.6	4.5
0.413	1	7.8	11.2
	2	8.1	11.2
(185)	3	8.1	11.2
	4	8.3	11.2
	5	8.6	11.1
	6	8.9	11.1
	7	8.9	10.9
0.647	1	12.2	17.6
	2	12.6	17.6
(290)	3	12.7	17.6
	4	13.0	17.5
	5	13.6	17.4
	6	14.0	17.5
	7	14.0	17.3
0.892	1	16.7	24.2
	2	17.3	24.2
(400)	3	17.4	24.3
	4	17.9	24.1
	5	18.6	24.0
	6	19.3	24.3
	7	19.3	24.0

NOTES: 1. Details of jet header are shown on plate 114 ; pipe sizes are nominal.

2. Velocities were measured 1/4 in. downstream from nozzles.

PRESSURES, DISCHARGES, AND COMPARATIVE AIR DEMAND

Fish Hatchery Aerators



AIR MEASUREMENT APPARATUS

Black Iron Pipe				PVC Plastic Pipe			
Header Pressure at Aerators PSI	Range of Header Discharge GPM	Discharge Per Aerator GPM	Air Velocity at Anemometer FPM	Header Pressure at Aerators PSI	Range of Header Discharge GPM	Discharge Per Aerator GPM	Air Velocity at Anemometer FPM
1 1/2-in. Aerator, 1 1/2-in. Nozzle, 3/4-in. Air Pipe							
5.0	152	76	154	4.5	114	57	
7.3	184	92		7.2			
10.0	212 - 3900	103 - 106	195	10.0	178 - 3920	88 - 89	
12.0	232	116		13.5	206	103	
15.0	260	130	234	17.4	232	116	
16.9	276	138		17.8	234	117	
2-in Aerator, 1 1/2-in. Nozzle, 3/4-in. Air Pipe							
5.0	164	82	140	5.0	156		129
7.3	196	98		7.3	188		
10.0	228 - 3898	107 - 115	201	10.0	220 - 3700	110	178
12.0	250	125		12.2	242	121	
15.0	278	139	245	15.0	270	135	219
17.5	300	150		16.9	288	144	
2-in. Aerator, 2-in. Nozzle, 3/4-in. Air Pipe							
5.0	330	165	157				
7.3	398	199					
10.0	458 - 4169	230 - 232	197				
12.0	504	252					
15.0	562	281	226				
16.8	598	299					
2-in. Aerator, 2-in. Nozzle, 1-in. Air Pipe							
5.0	270	135	207	5.0	228	114	242
7.4	326	163		7.6	282	141	
10.0	374 - 3799	187 - 190	290	10.0	324 - 3700	162 - 164	309
12.0	408	204		12.3	356	178	
15.0	458	229	351	15.0	392	196	364
17.0	486	243		16.8	414	207	

NOTE: Details of aerators and test stand are shown on plates 115 and 117.

TABLE P

AIR DISCHARGES

Fish Hatchery Aerators

Aerator Diameter Inches	Nozzle Diameter Inches	Air Pipe Diameter Inches	Header Pressure PSI	Discharge Per Aerator: Water GPM	Water CFS	Air at Anemometer CFS	Air at Anemometer CFS/CFS Water
			Black Iron Pipe				
1 1/2	1 1/2	3/4	5	76	0.169	0.238	1.41
			10	106	0.236	0.302	1.28
			15	130	0.290	0.362	1.25
2	1 1/2	3/4	5	82	0.183	0.217	1.18
			10	114	0.254	0.311	1.22
			15	139	0.310	0.379	1.22
2	2	3/4	5	165	0.368	0.243	0.66
			10	230	0.512	0.305	0.60
			15	281	0.626	0.350	0.56
2	2	1	5	135	0.301	0.320	1.06
			10	187	0.417	0.449	1.08
			15	229	0.510	0.543	1.06
			PVC Plastic Pipe				
2	1 1/2	3/4	5	78	0.174	0.200	1.15
			10	110	0.245	0.275	1.12
			15	135	0.301	0.339	1.12
2	2	1	5	114	0.254	0.374	1.47
			10	162	0.361	0.478	1.32
			15	196	0.437	0.563	1.29

NOTES: 1. Air discharges were computed from velocities listed in table O.

2. Details of aerators are shown on plate 117.

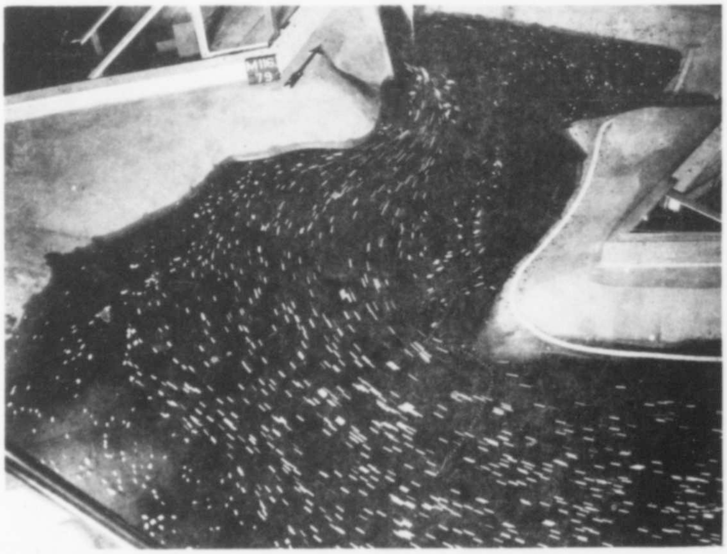
TABLE Q

PRESSURES AND DISCHARGES

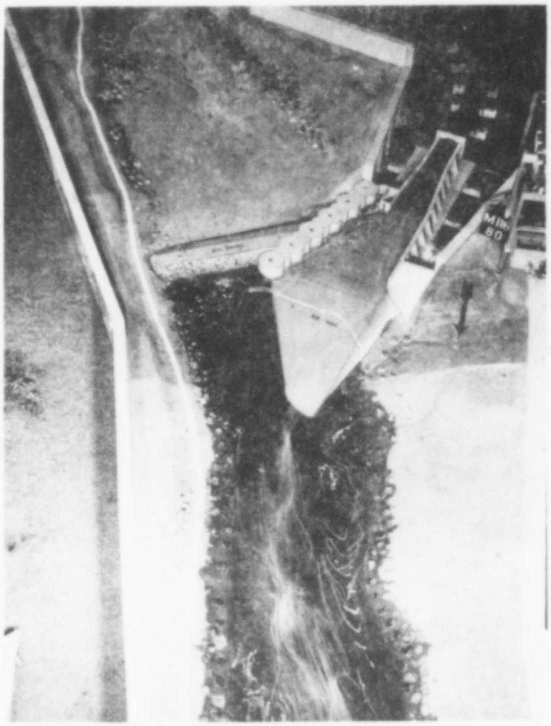
Fish Hatchery Deaerators

Black Iron Pipe			PVC Plastic Pipe		
Header Pressure at Deaerators PSI	Range of Header Discharge GPM	Discharge per Deaerator GPM	Header Pressure at Deaerators PSI	Range of Header Discharge GPM	Discharge per Deaerators GPM
1 1/2-in. Deaerator, 1 1/2-in. Nozzle					
5.0	238	119	4.8	212	106
7.7	286	143	7.5	264	132
10.0	324 - 2475	162 - 167	10.0	302 - 2436	149 - 157
12.0	352	176	12.0	328	164
15.0	390	195	15.0	364	182
17.5	424	212	16.8	386	193
1 1/2-in. Deaerator, 1 1/4-in. Nozzle					
5.0	196	98	5.0	188	94
7.5	234	117	7.5	224	112
10.0	266 - 2472	133 - 136	10.0	256 - 2466	128 - 131
12.0	290	145	12.0	278	139
15.0	324	162	15.0	310	155
16.7	342	171	16.8	328	164
1 1/2-in. Deaerator, 1-in. Nozzle					
5.0	110	55	5.0	104	52
7.5	130	65	7.8	128	64
10.0	150 - 2466	75 - 76	10.0	144 - 2418	72 - 74
12.0	162	81	12.0	158	79
15.0	182	91	15.0	176	88
16.8	194	97	16.8	188	94
2-in. Deaerator, 1 1/4-in. Nozzle					
5.3	228	114	4.5	184	92
7.5	266	133	7.5	232	116
10.0	302 - 2427	151 - 154	10.0	266 - 2468	133 - 139
12.0	328	164	12.0	290	145
15.0	364	182	15.0	328	164
16.9	386	193	16.9	346	173

NOTE: Details of deaerators and test stand are shown on plates 118 and 119 .

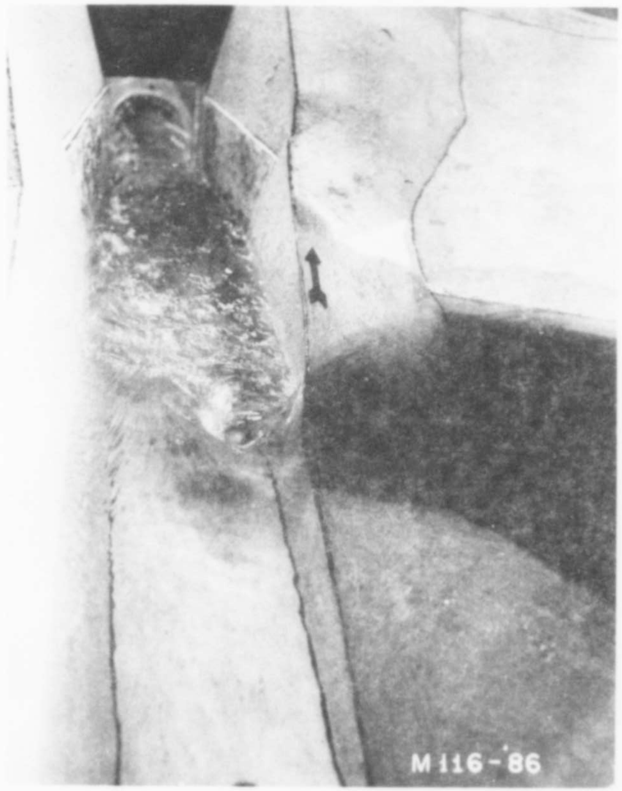


Upstream cofferdam and intake.

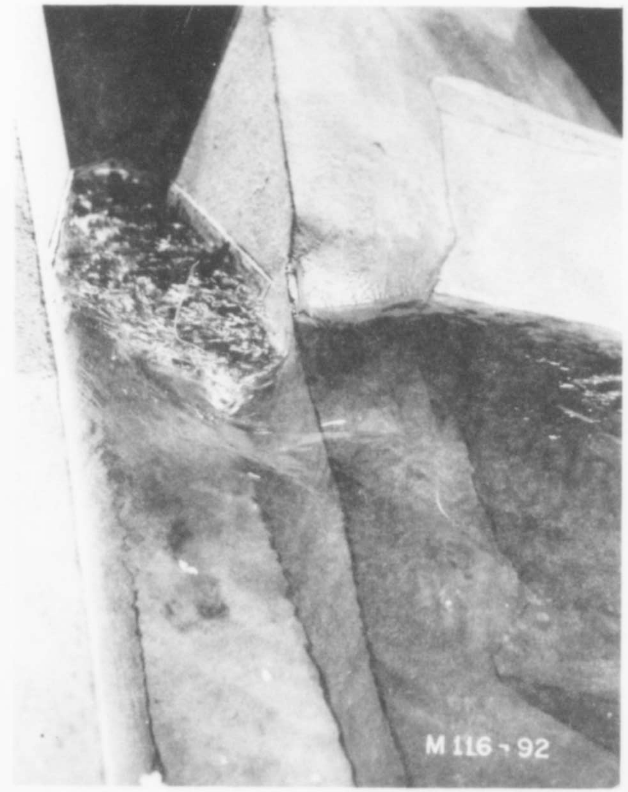


Downstream cofferdam and outlet.

Photograph 1. Flow patterns with plan A diversion tunnel (original design); river discharge 40,000 cfs, average tailwater elevation 984.5.

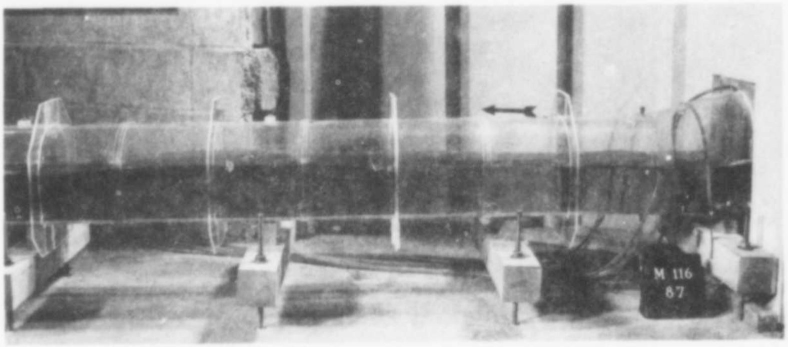


River discharge 20,000 cfs.

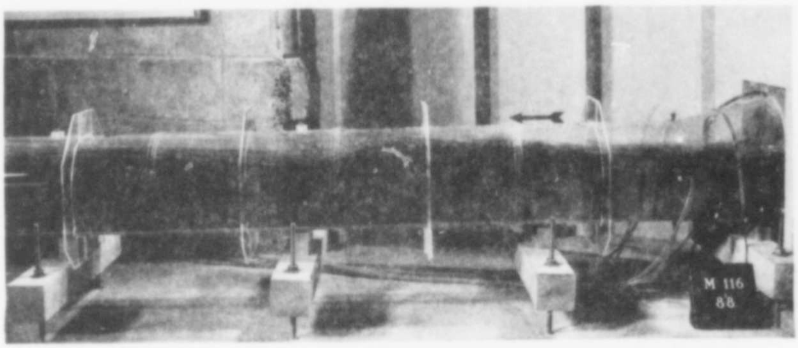


River discharge 40,000 cfs.

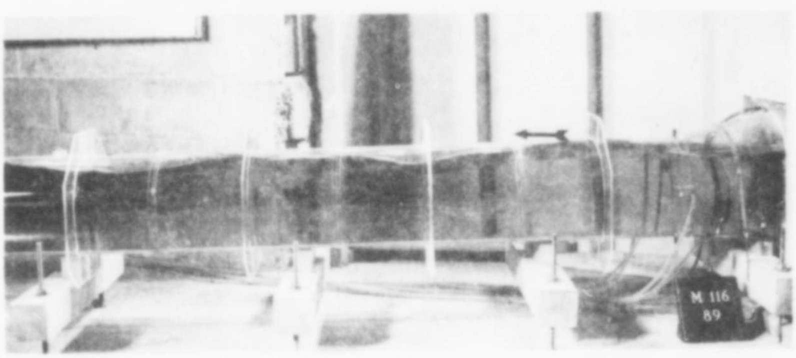
Photograph 2. Turbulence at intake of plan A diversion tunnel.



20,000 cfs

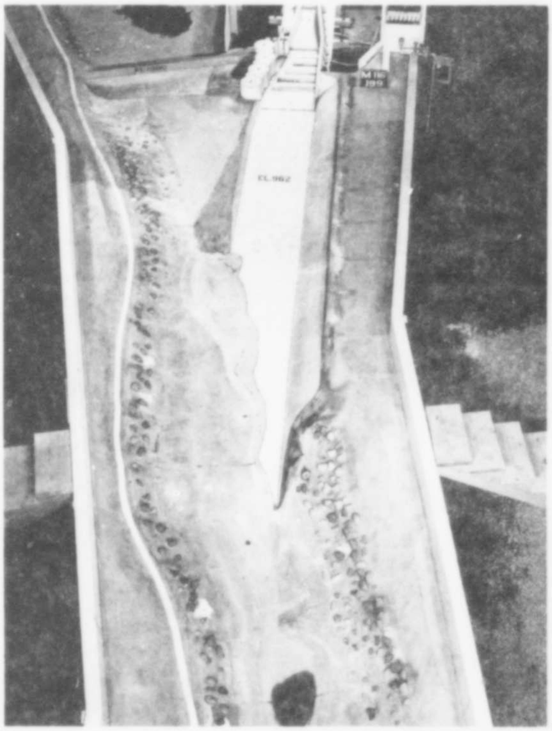


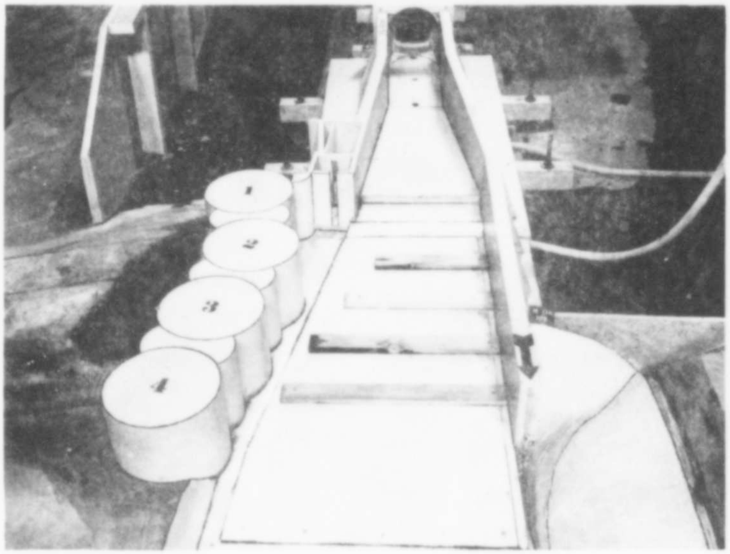
30,000 cfs



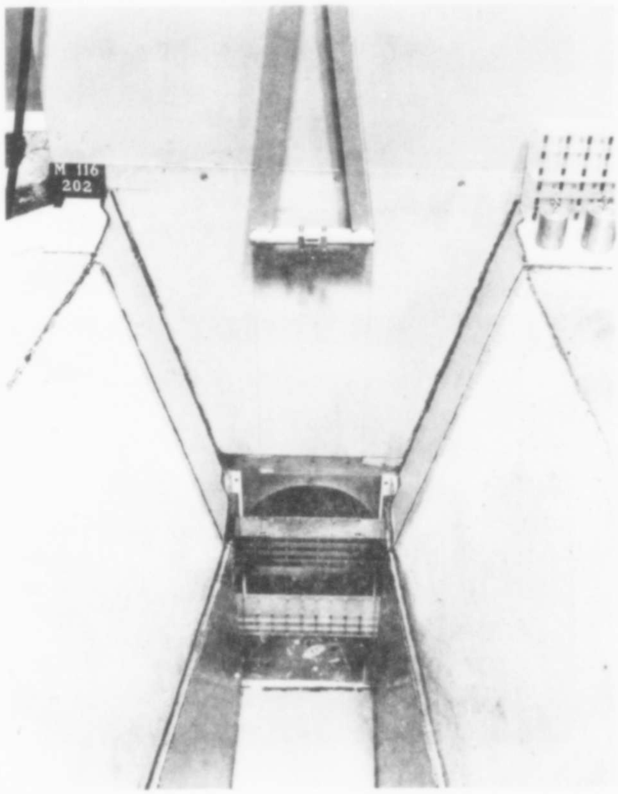
35,000 cfs

Photograph 3. Flow conditions just downstream from intake of plan A diversion tunnel.

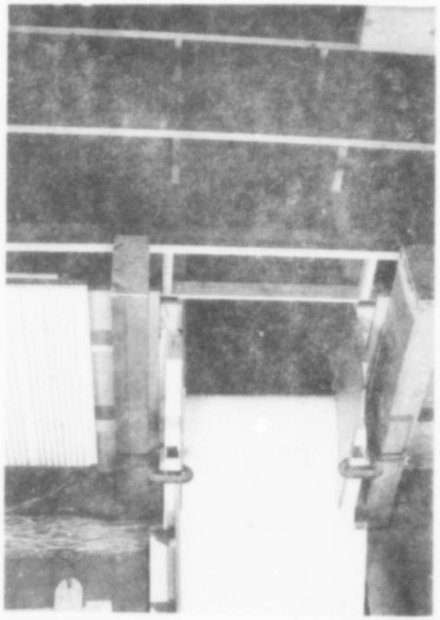




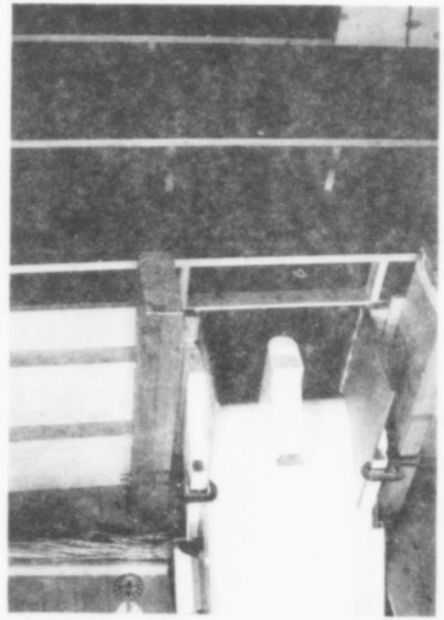
Photograph 4. Plan J diversion tunnel outlet (final design).



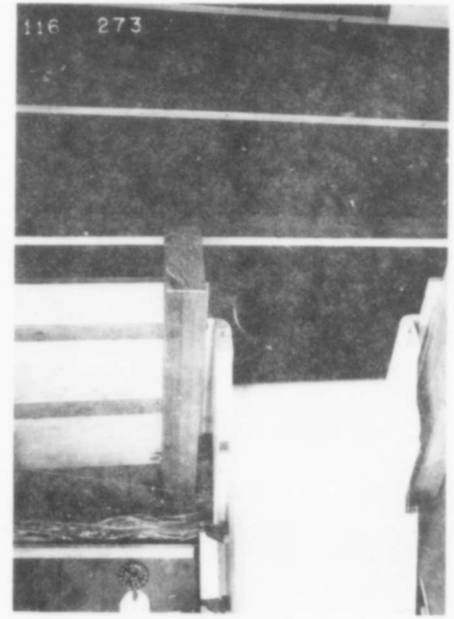
Photograph 5. Tunnel entrance with closure rack in slots, cable suspension, and part of lowering device.



Crest with false walls

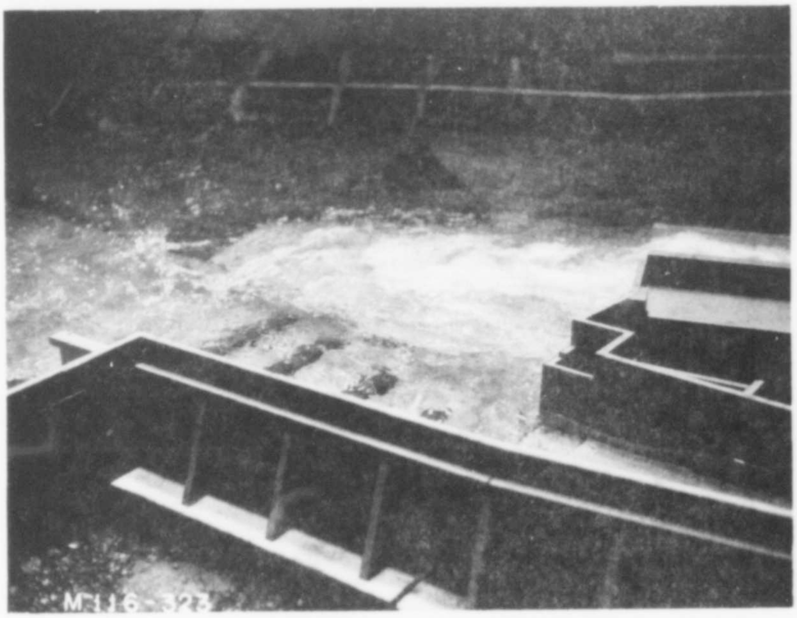


Crest and abutments

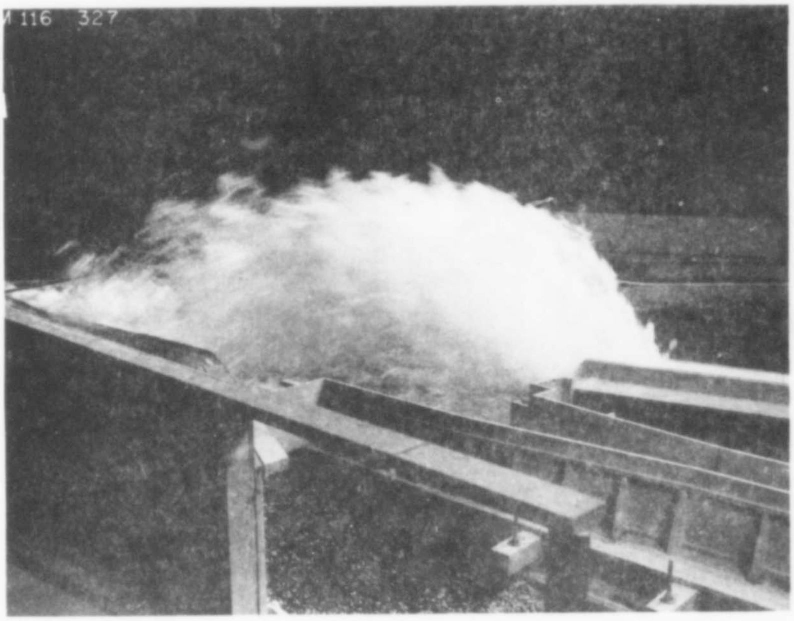


Crest with pier and false walls

Photograph 6. Elements of plan A (original design) spillway installed to determine discharge coefficients.

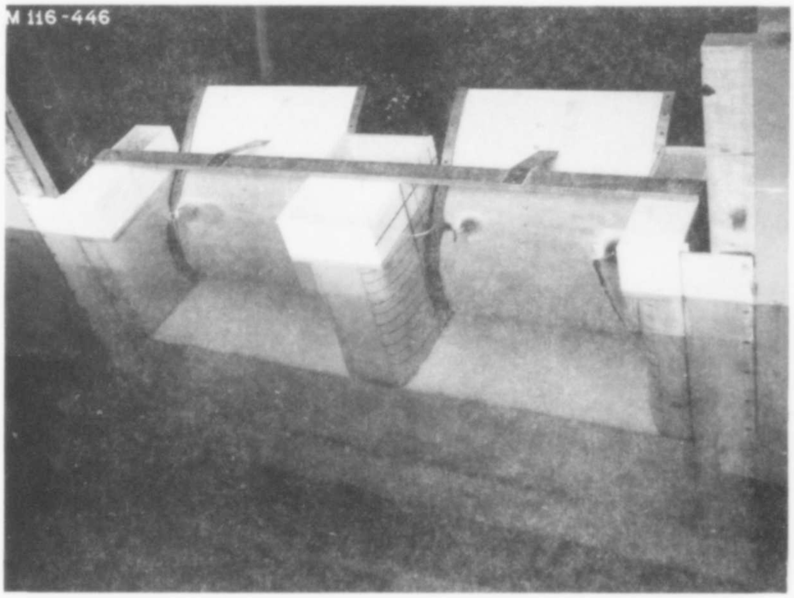


Spillway discharge 40,000 cfs, river discharge 45,000 cfs.

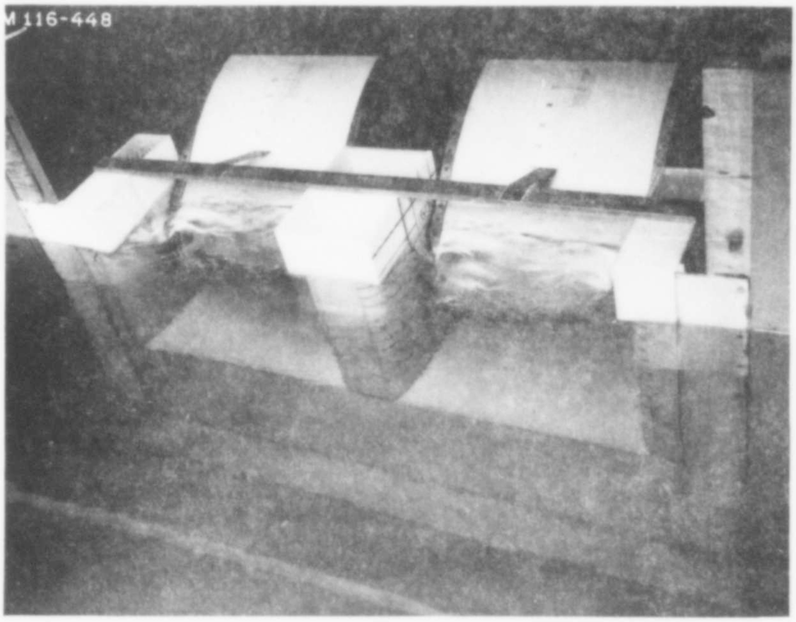


River and spillway discharge 90,000 cfs.

Photograph 7. Flow conditions downstream from plan A stilling basin (original design).

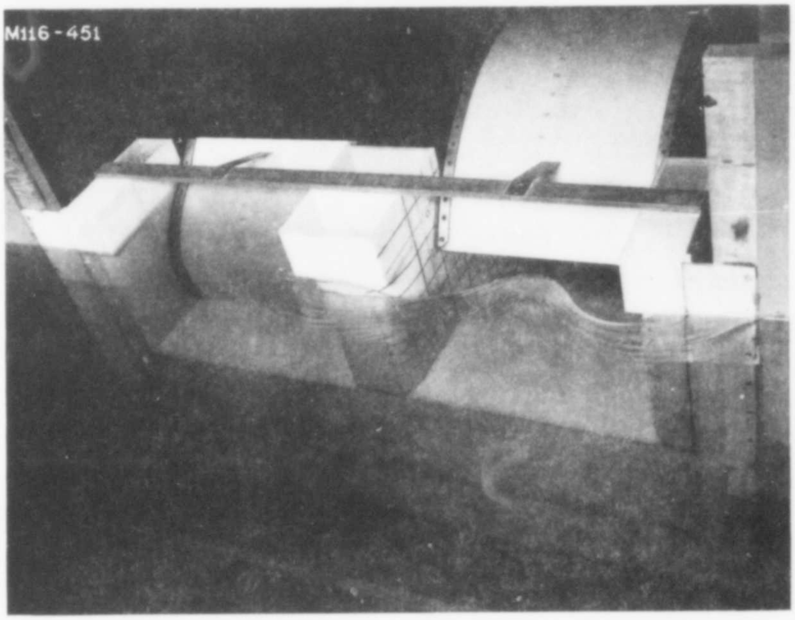


Gates open 10.8 ft, discharge 40,000 cfs.
(Note vortices at sides of gates).

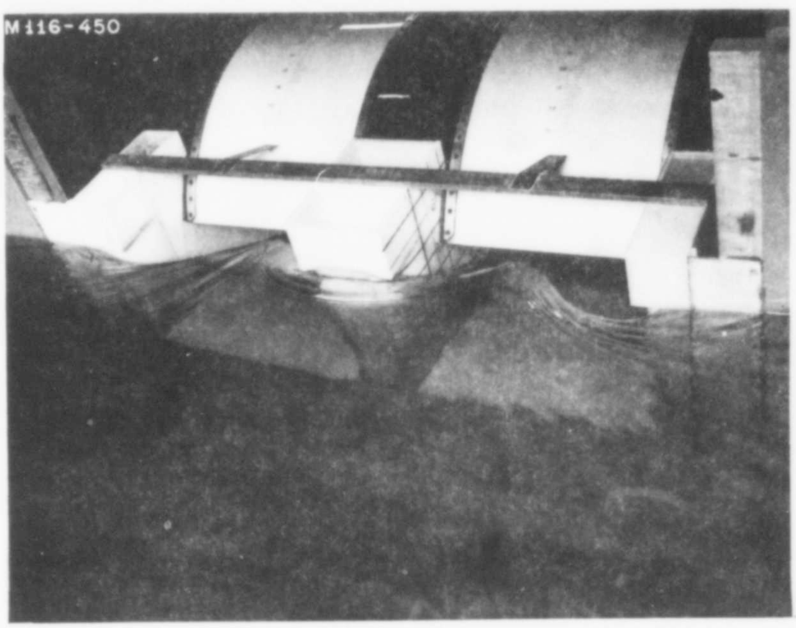


Gates open 25.0 ft, discharge 90,000 cfs.

Photograph 8. Flow conditions at plan C spillway pier and abutments (final design). Gated flow, pool elevation 1,600.0.

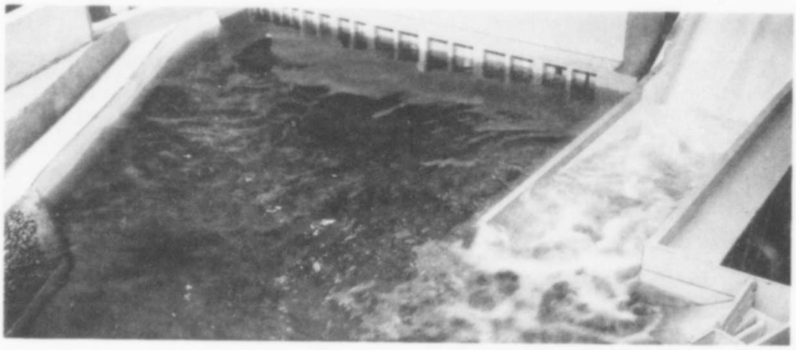


Discharge 80,000 cfs through right bay.

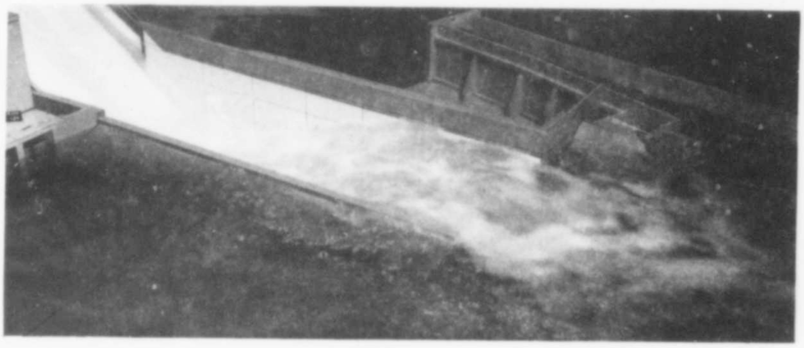


Discharge 157,200 cfs through both bays.

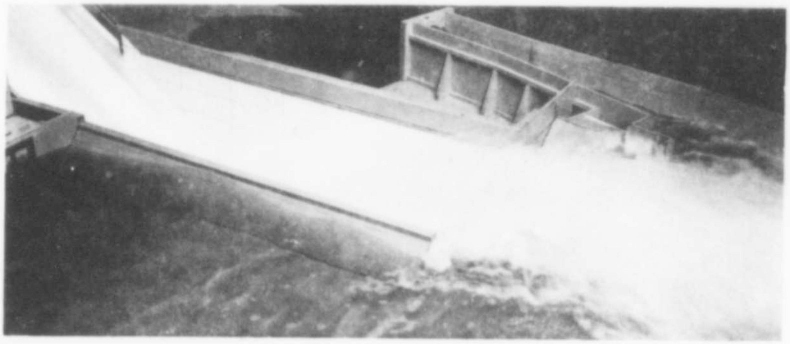
Photograph 9. Flow conditions at plan C spillway pier and abutments (final design). Free flow, pool elevation 1,600.0.



River discharge 45,000 cfs, spillway flow 40,000 cfs.

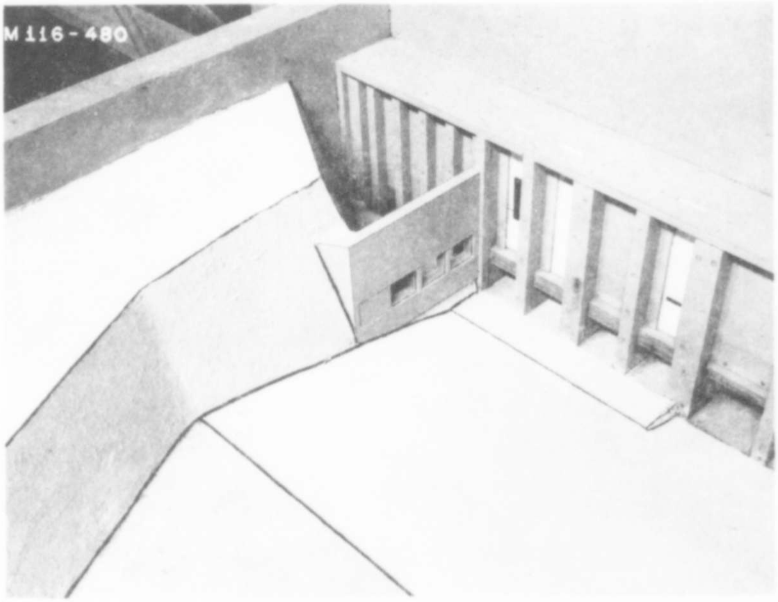


River discharge 50,000 cfs, spillway flow 45,000 cfs.

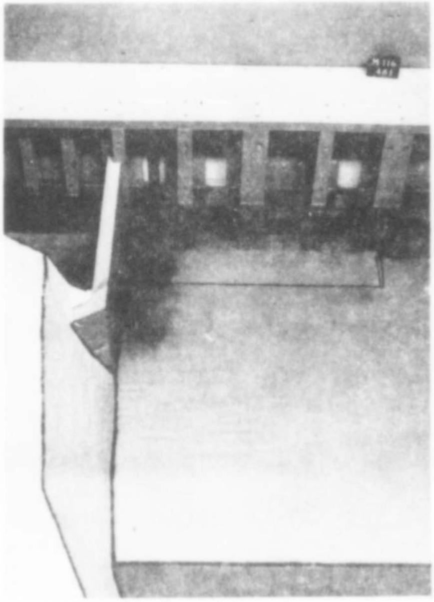


River discharge 90,000 cfs, spillway flow 85,000 cfs.

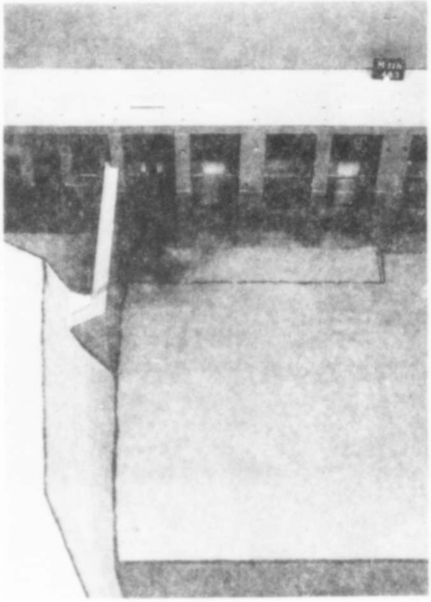
Photograph 10. Flow conditions in plan B-2 stilling basin (final design).



Drybed view looking upstream.

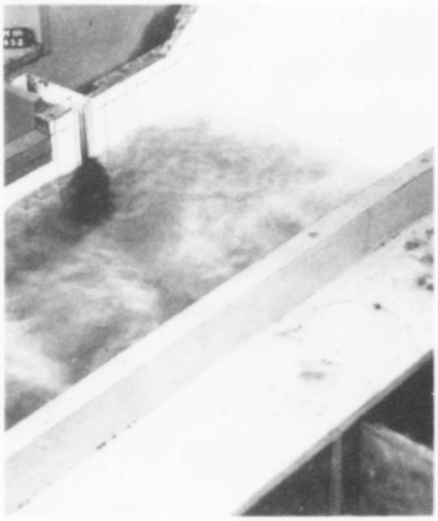


Unit 1 operating; discharge 2,500 cfs, tailwater elevation 969.6.

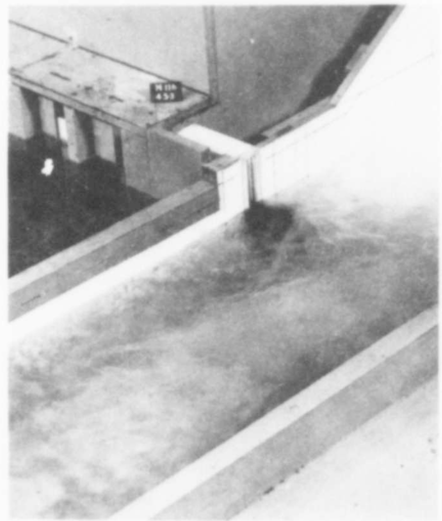


Units 1 to 3 operating; discharge 10,500 cfs, tailwater elevation 976.8.

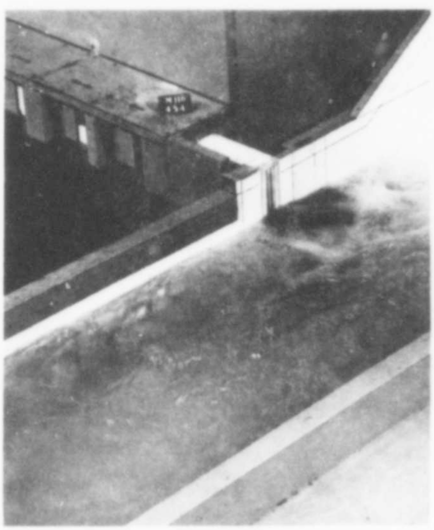
Photograph 11. Plan C pump intake and right bank (final design). The bottom pictures show dye paths of attraction flow from fish collection system.



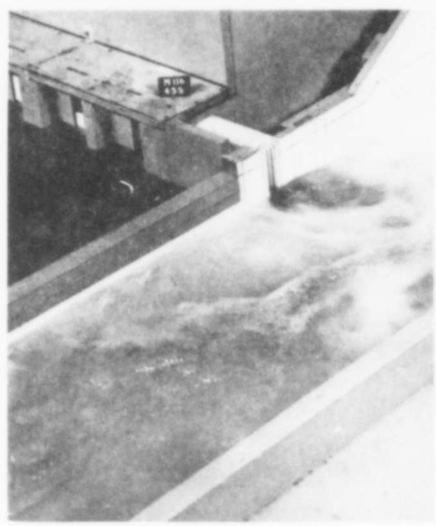
Spillway flow 2,500 cfs.



Spillway flow 5,000 cfs.



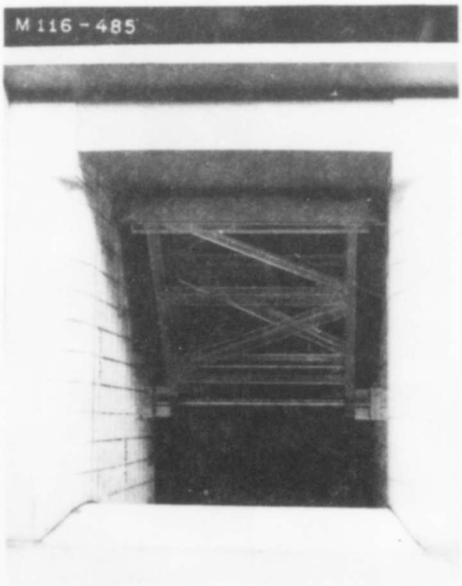
Spillway flow 7,500 cfs.



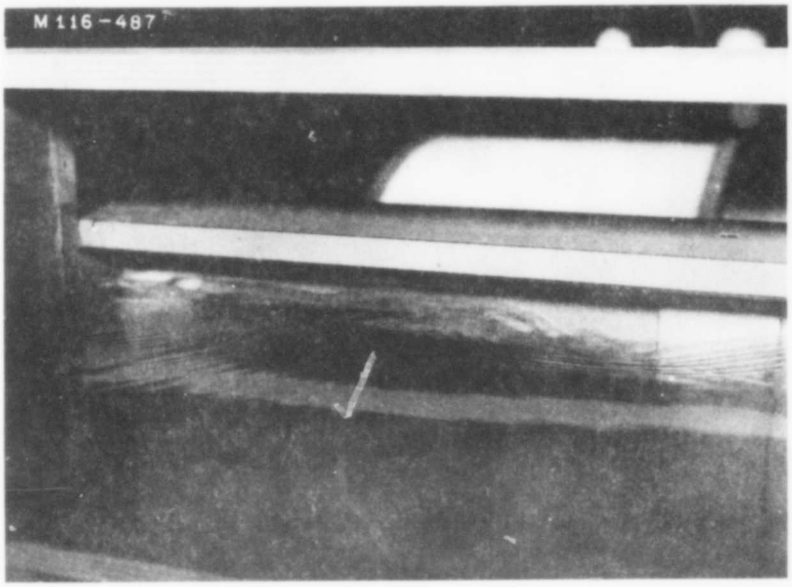
Spillway flow 10,000 cfs.

Photograph 12. Flow conditions at fishway entrance in right wall of plan B-2 stilling basin. Powerhouse discharge 10,500 cfs, fishway flow 120 cfs.

Upstream face of spillway bay without bridge.

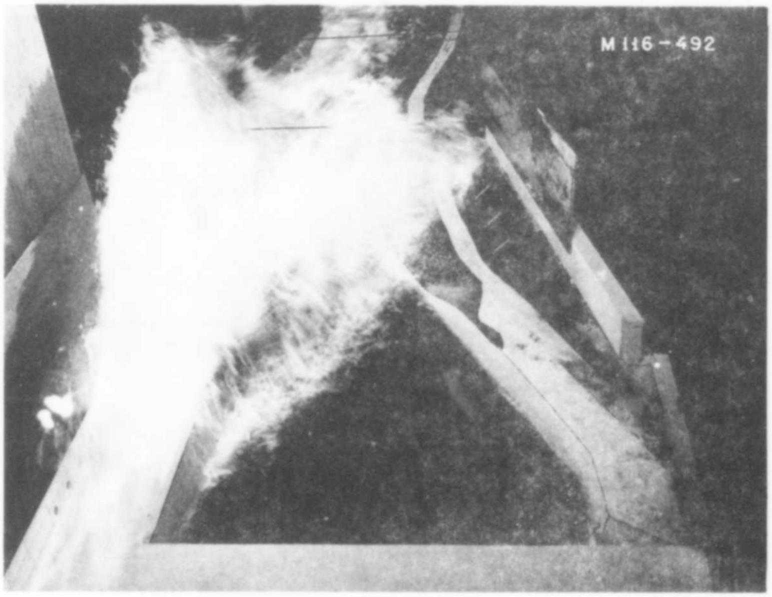


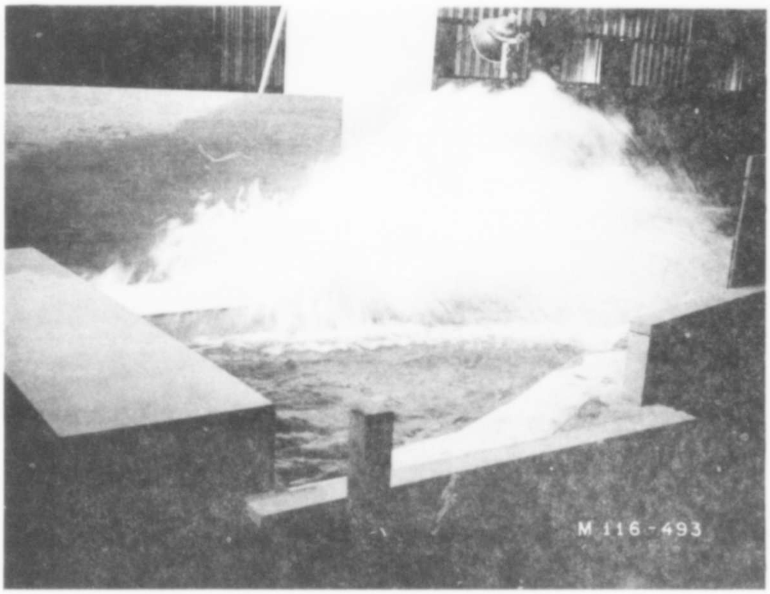
Upstream face of spillway bay with bridge.



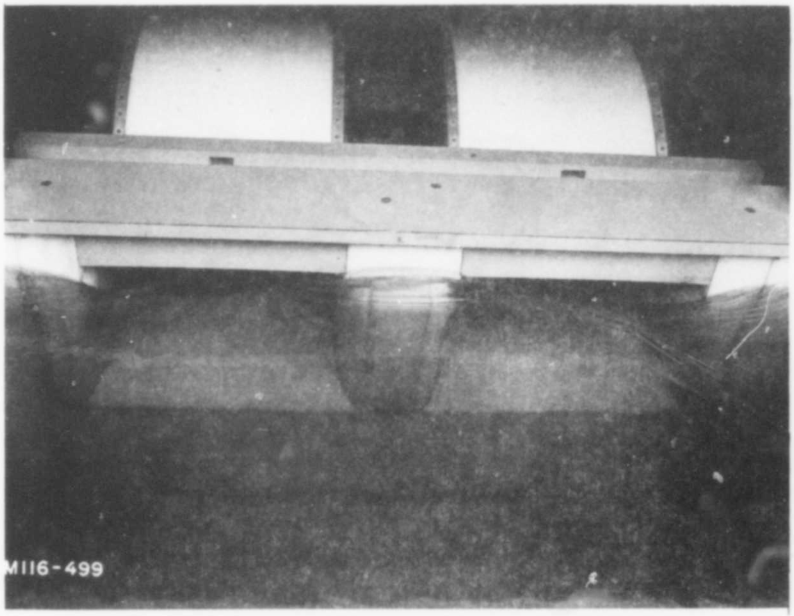
Orifice flow at upstream side of bridge.
Pool elevation 1,611.0, discharge 102,000 cfs in a single bay.

Photograph 13. Effect of contract plan spillway bridge on flow conditions at revised spillway design discharge of 205,000 cfs.

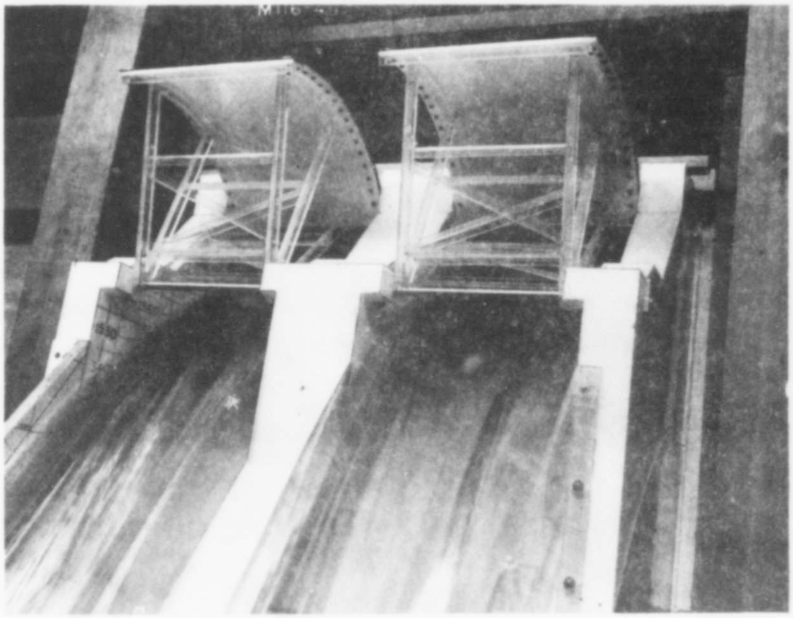




Photograph 14. Stilling basin sweepout with plume about 250 ft high. River discharge 257,000 cfs, spillway flow 208,000 cfs, conduit flow 41,000 cfs, and powerhouse flow 8,000 cfs.

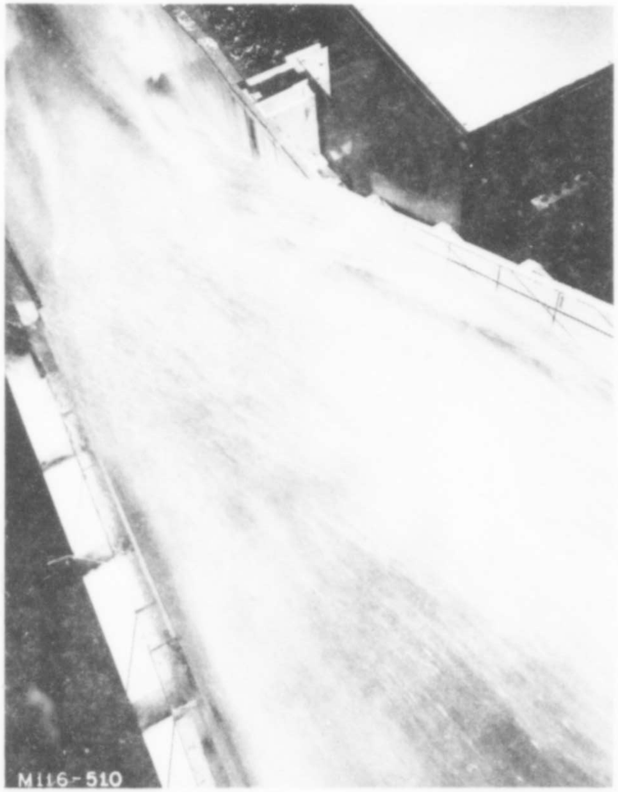


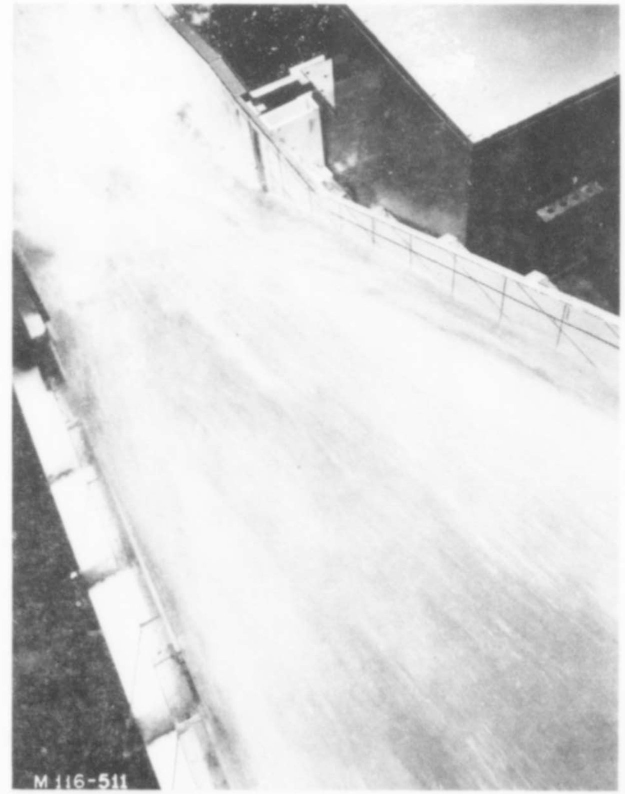
Flow underneath contract plan spillway bridge.



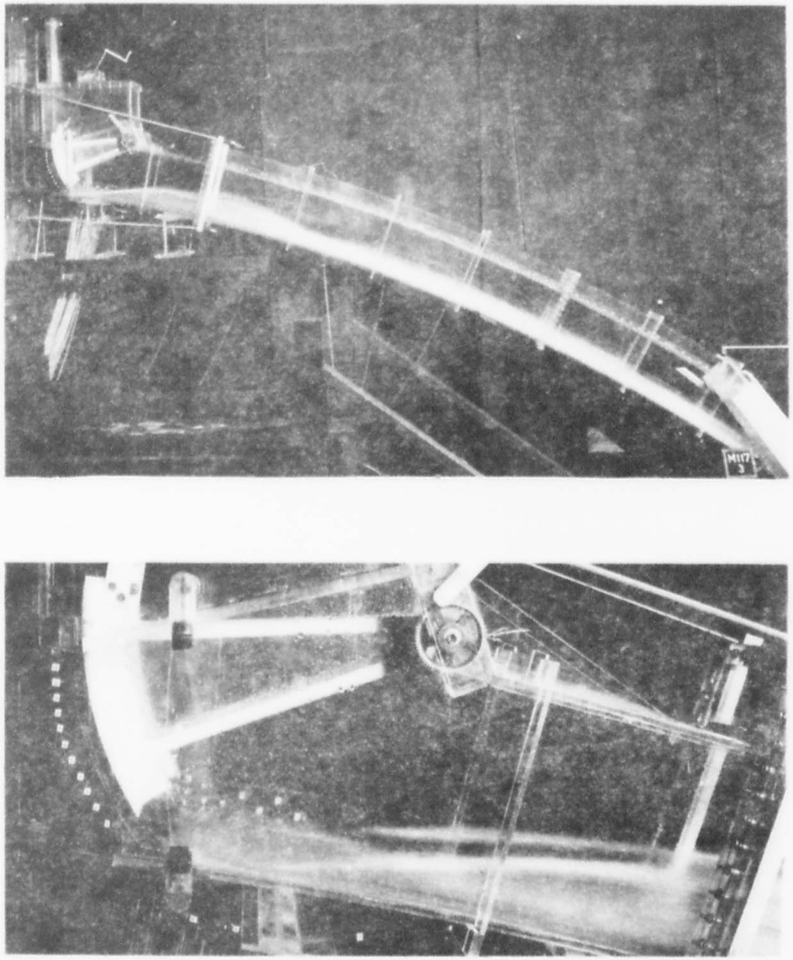
Flow in upper portion of plan D-1 chute.

Photograph 15. Flow conditions at spillway bridge and in upper portion of chute; free flow, 181,000 cfs, pool elevation 1,604.9.

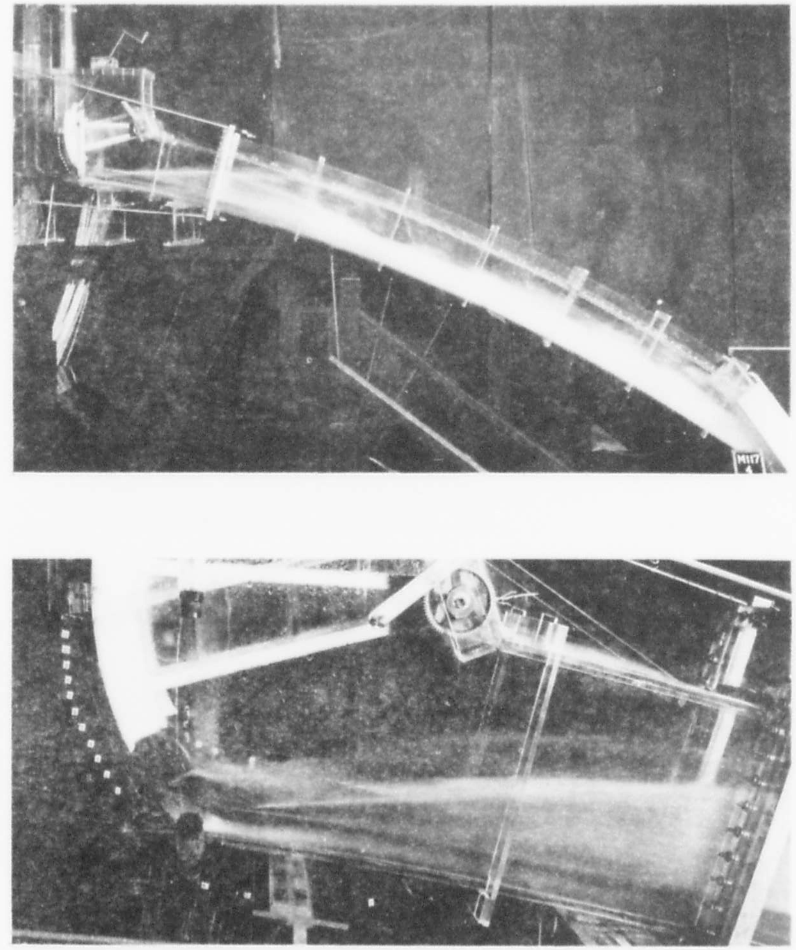




Photograph 16. Fluctuating nappe along right wall of plan D-1 spillway chute. Top of wall is indicated by the black line. Free flow, 181,000 cfs, pool elevation 1,604.9.

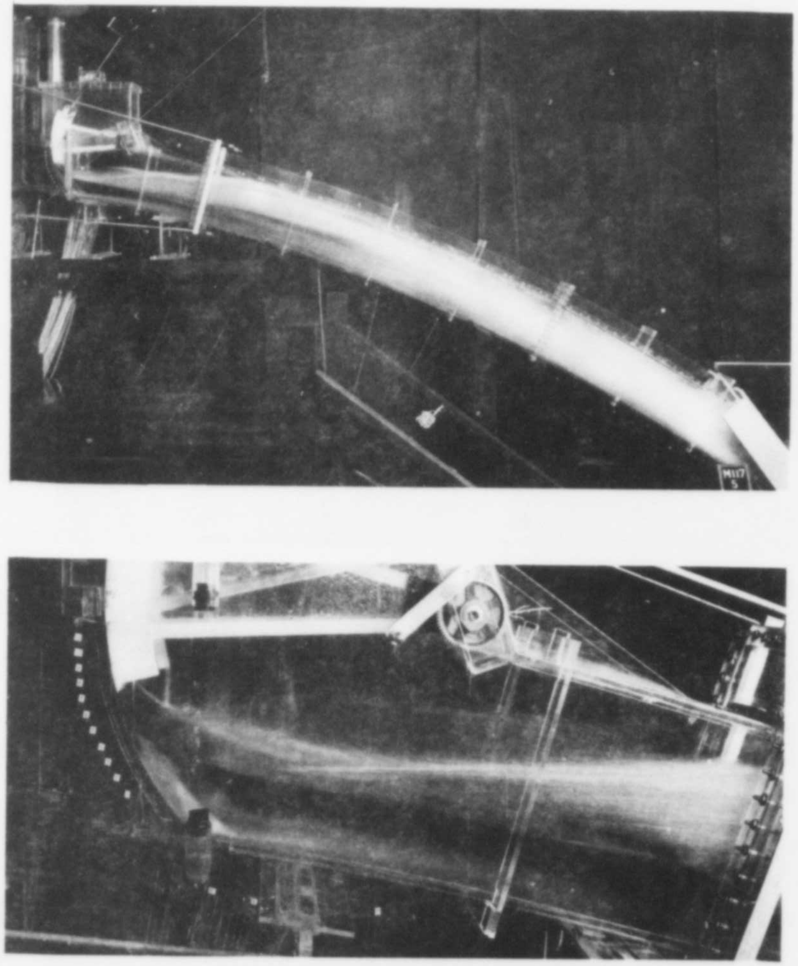


Valve open 2.0 ft; discharge 1,750 cfs.

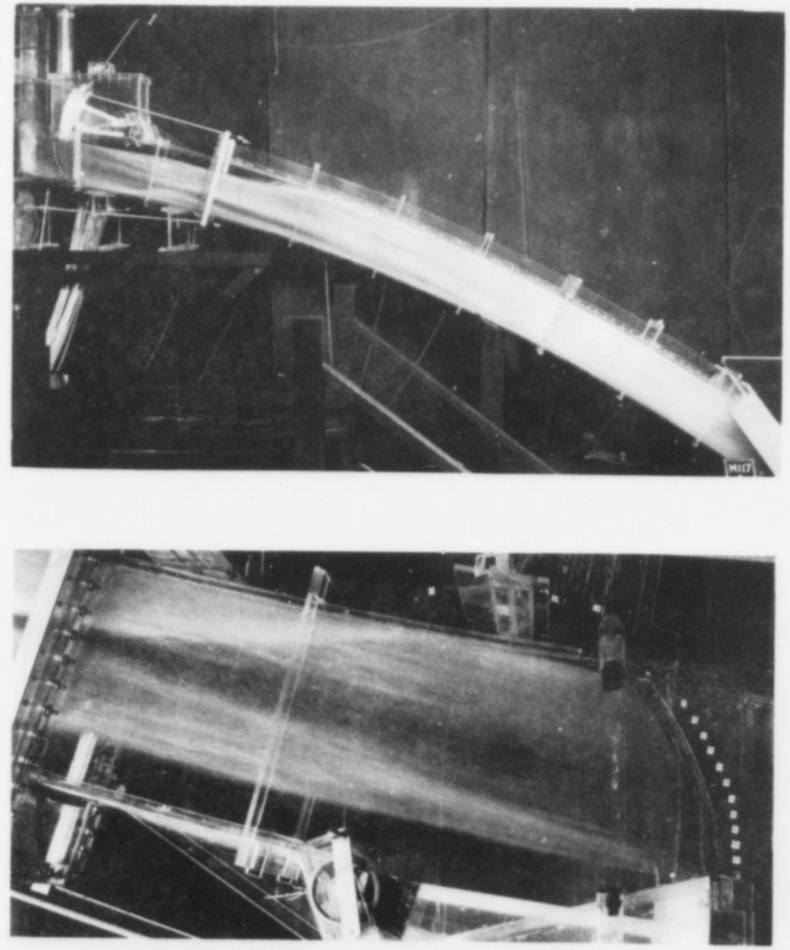


Valve open 4.0 ft; discharge 3,330 cfs.

Photograph 17. Flow in plan A conduit (original design); pool elevation 1,600.0, emergency gate slot vent closed.

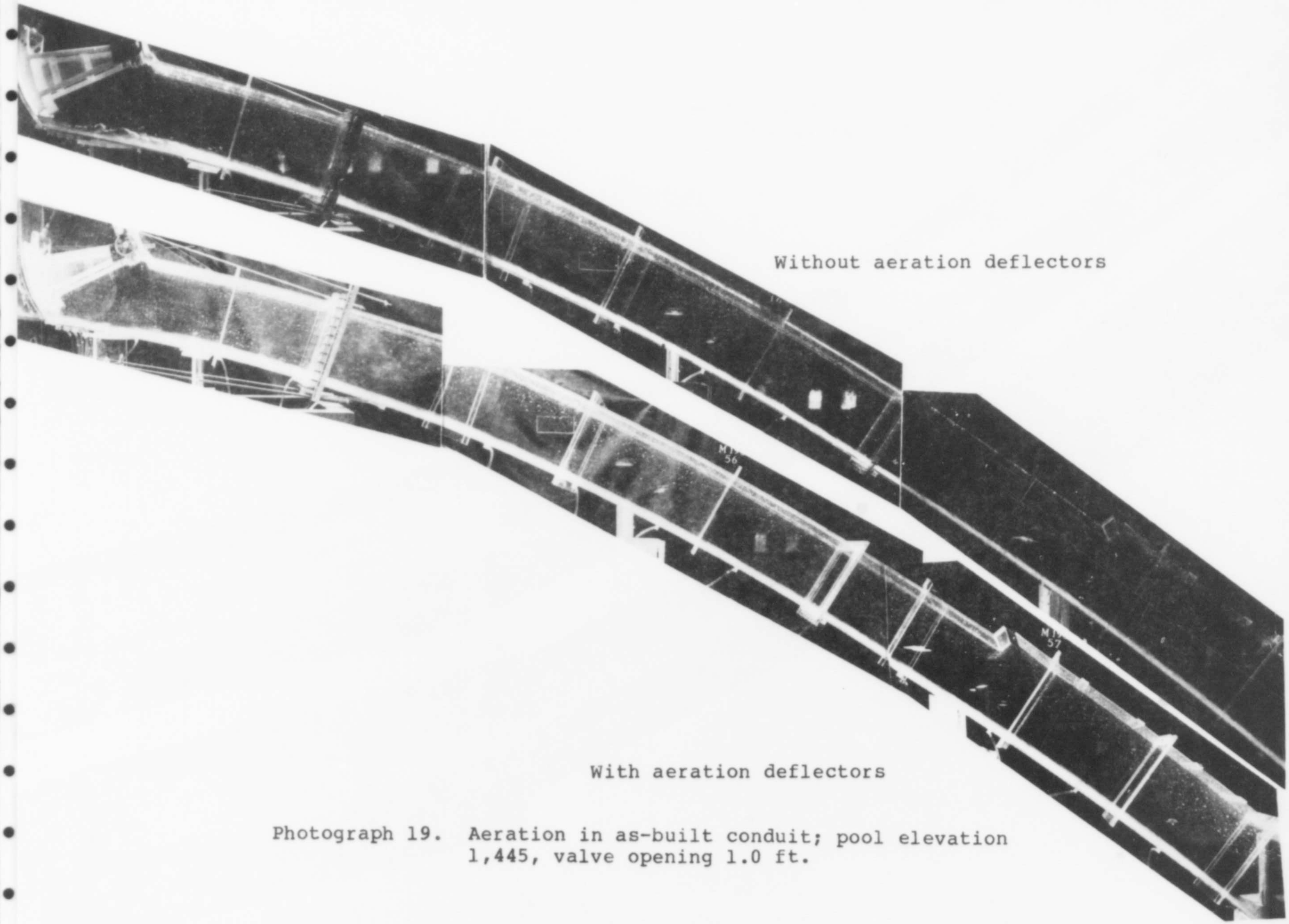


Valve open 8.0 ft; discharge 6,680 cfs; emergency gate slot vent closed.

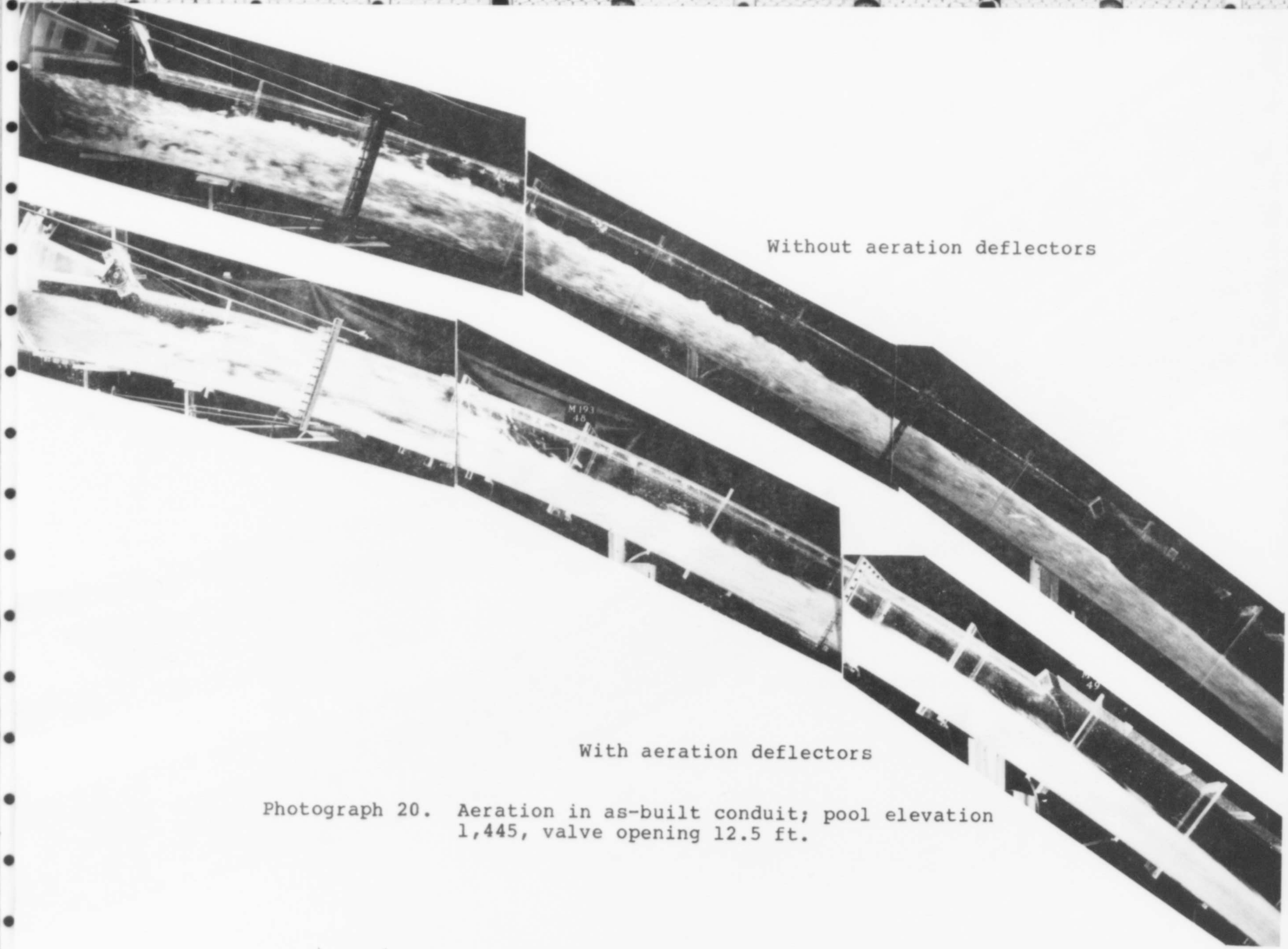


Valve open 12.5 ft; discharge 13,900 cfs. emergency gate slot vent open.

Photograph 18. Flow in plan A conduit (original design); pool elevation 1,600.0.



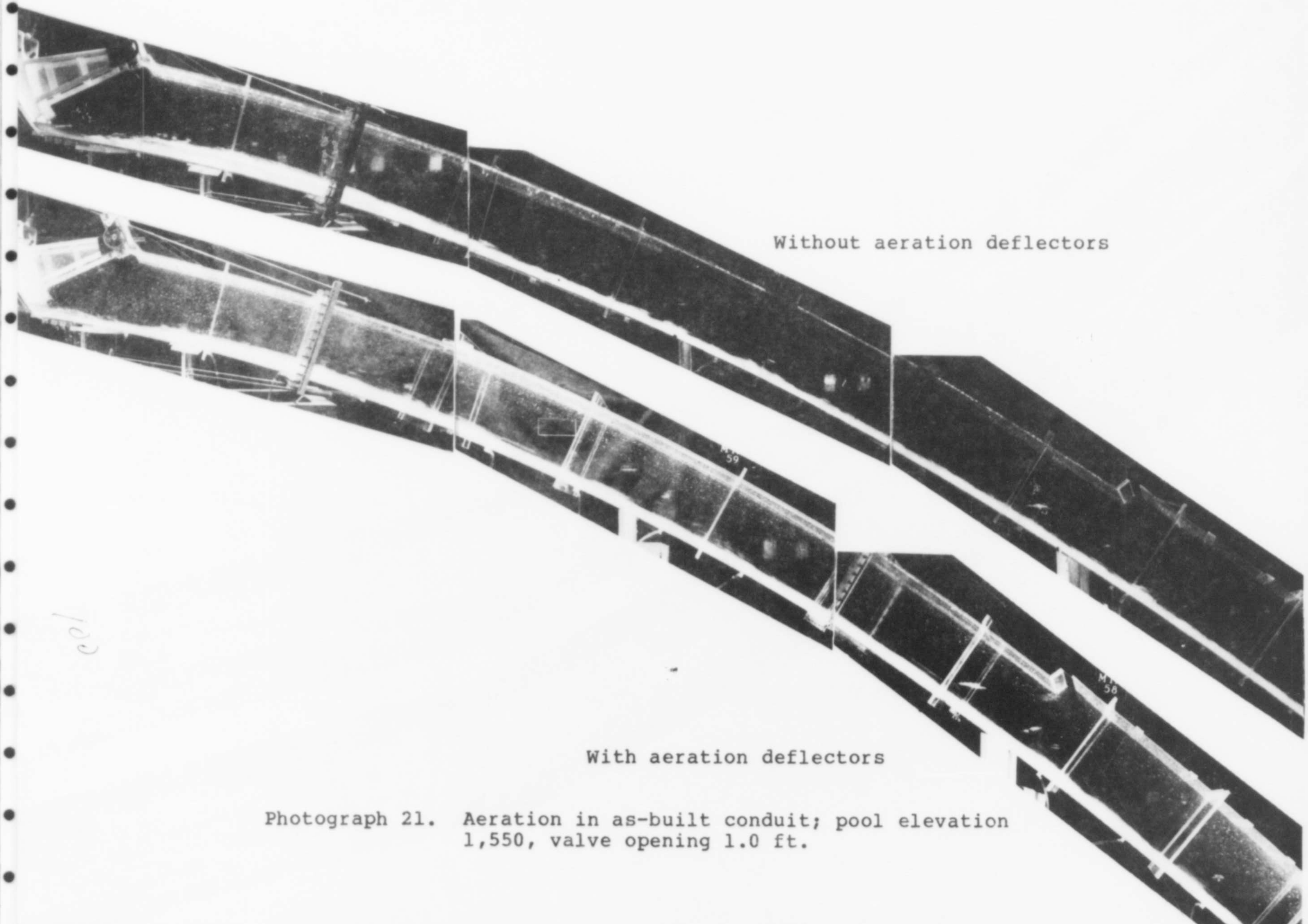
Photograph 19. Aeration in as-built conduit; pool elevation 1,445, valve opening 1.0 ft.



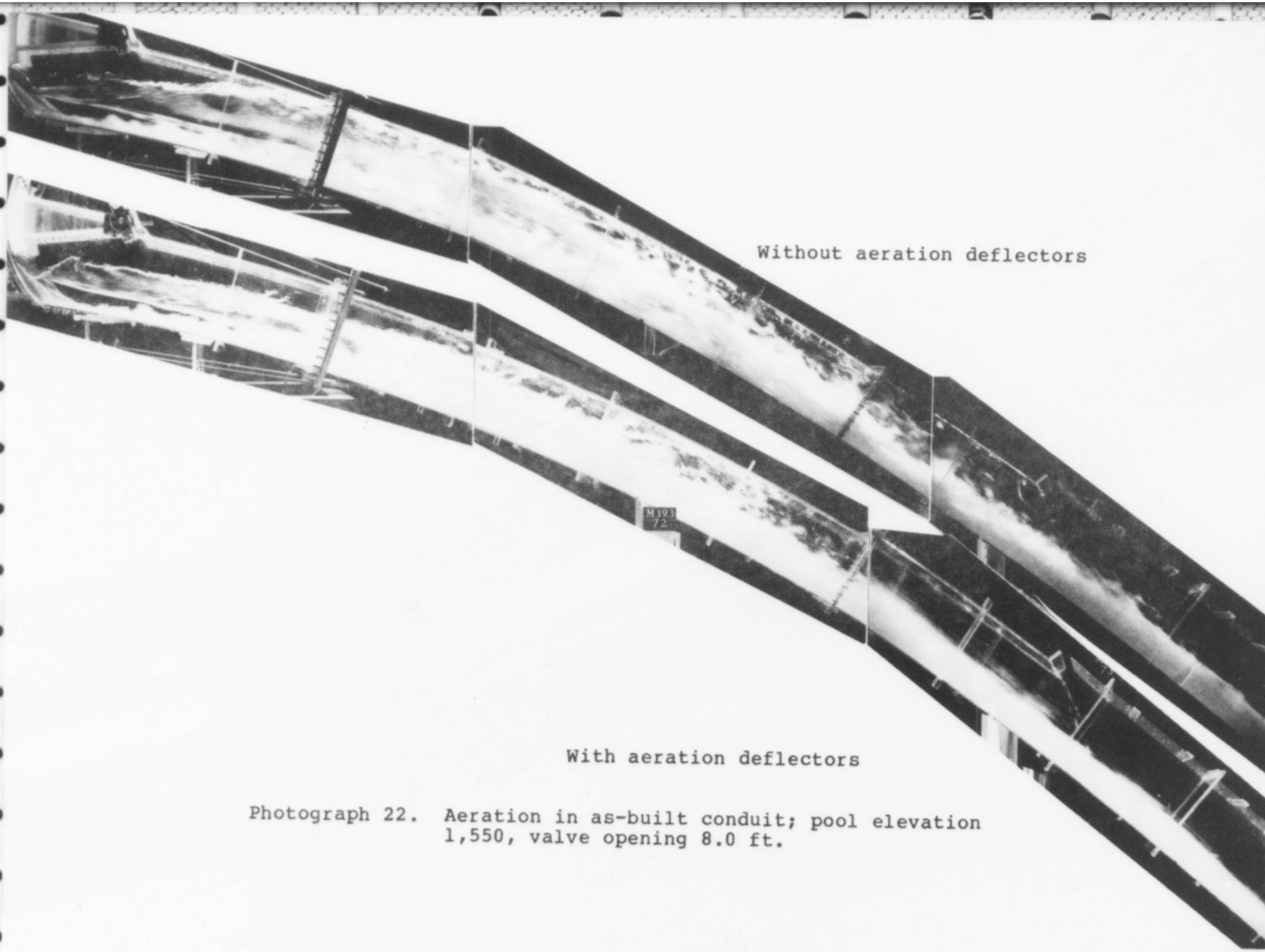
Without aeration deflectors

With aeration deflectors

Photograph 20. Aeration in as-built conduit; pool elevation 1,445, valve opening 12.5 ft.



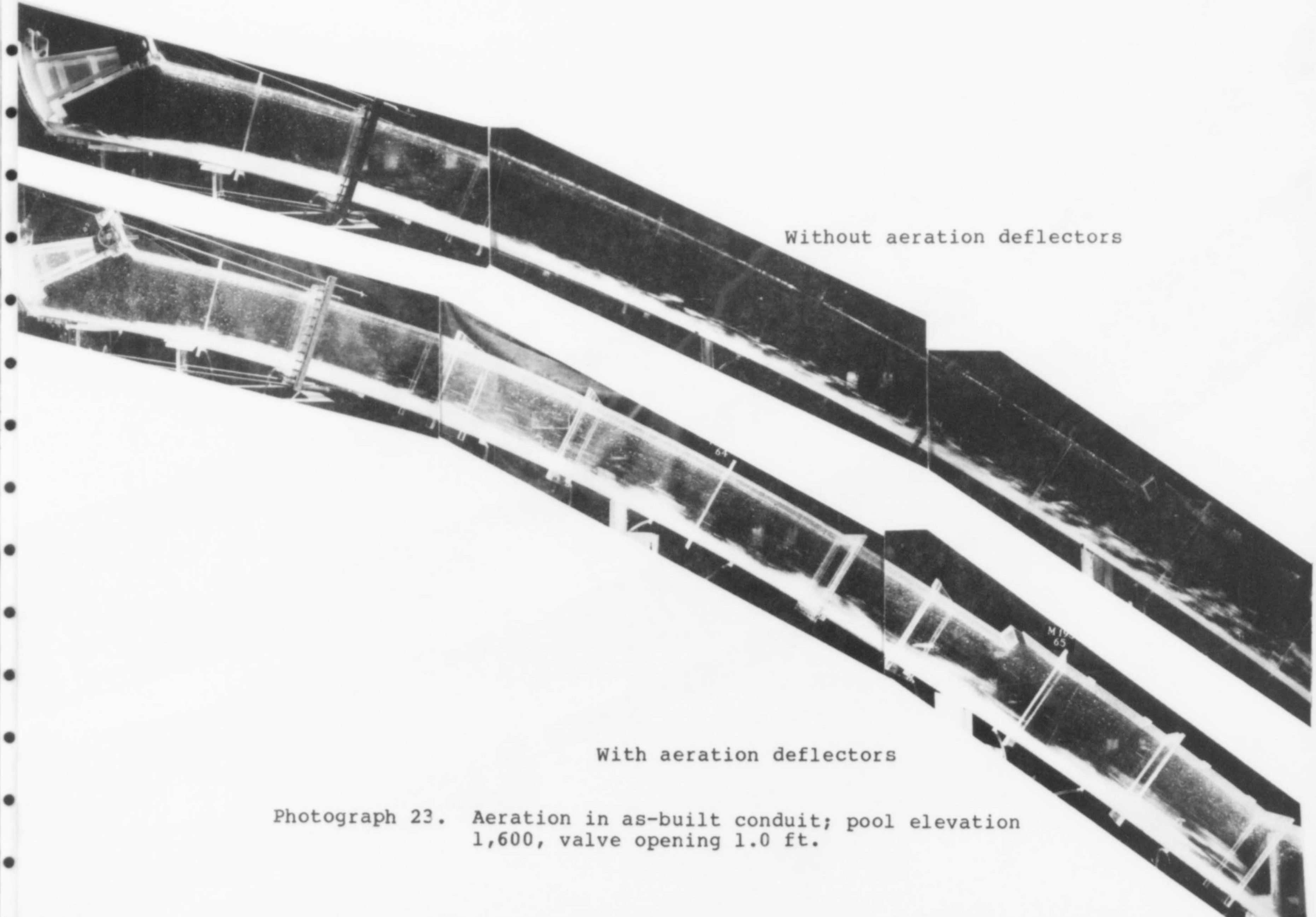
Photograph 21. Aeration in as-built conduit; pool elevation 1,550, valve opening 1.0 ft.



Without aeration deflectors

With aeration deflectors

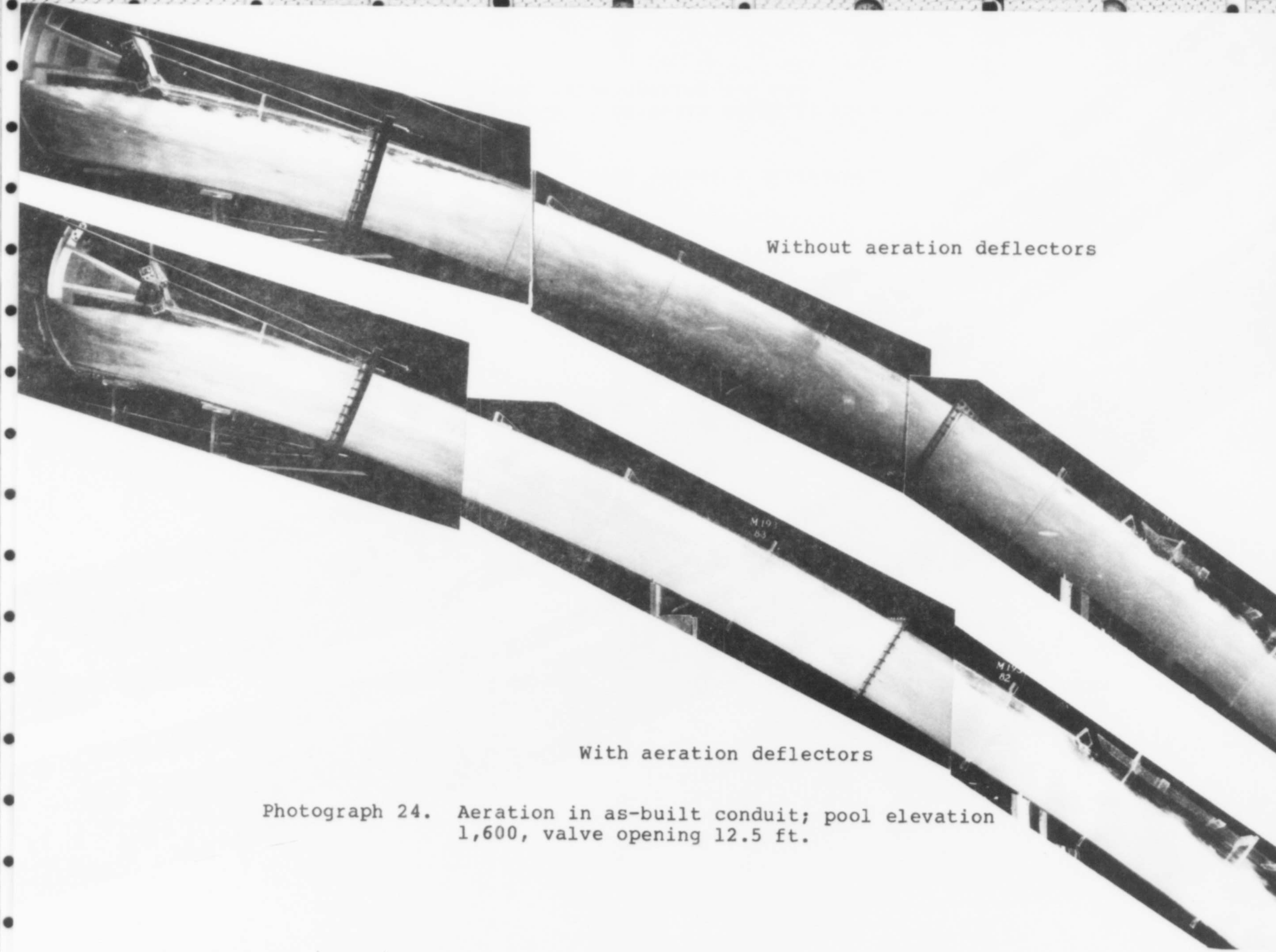
Photograph 22. Aeration in as-built conduit; pool elevation 1,550, valve opening 8.0 ft.



Without aeration deflectors

With aeration deflectors

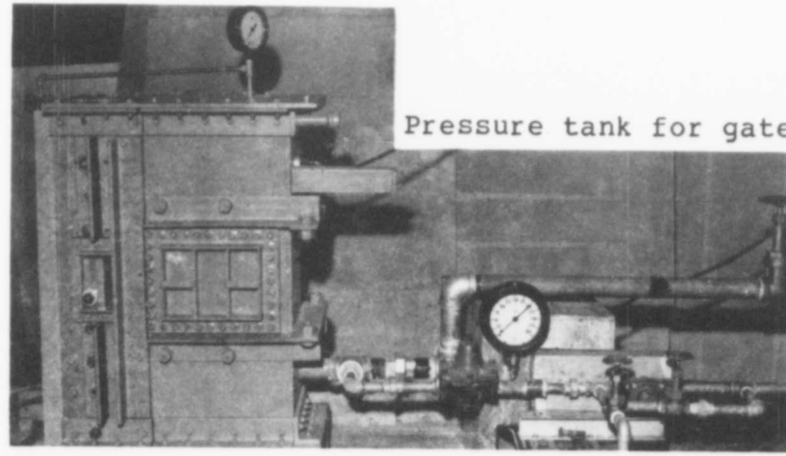
Photograph 23. Aeration in as-built conduit; pool elevation 1,600, valve opening 1.0 ft.



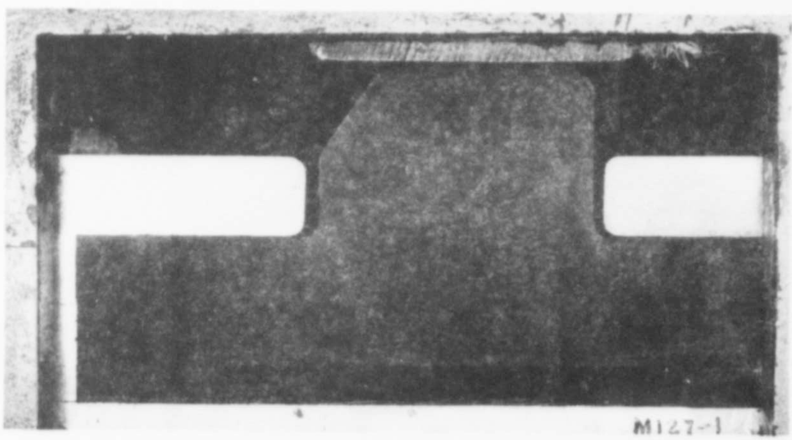
Without aeration deflectors

With aeration deflectors

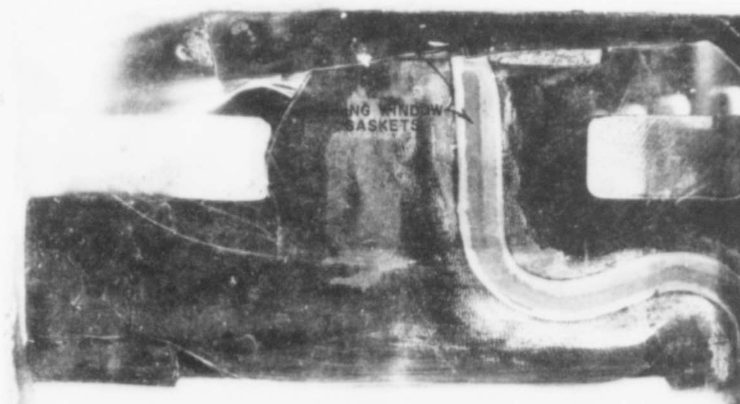
Photograph 24. Aeration in as-built conduit; pool elevation 1,600, valve opening 12.5 ft.



Pressure tank for gate seal tests.



Type 1 seal before tests.



Type 1 seal compressed 3/8 inch
under 300 ft. of head.

Photograph 25. Views taken during tests to determine sealing characteristics of rubber seals used with eccentric-trunnion tainter valves.

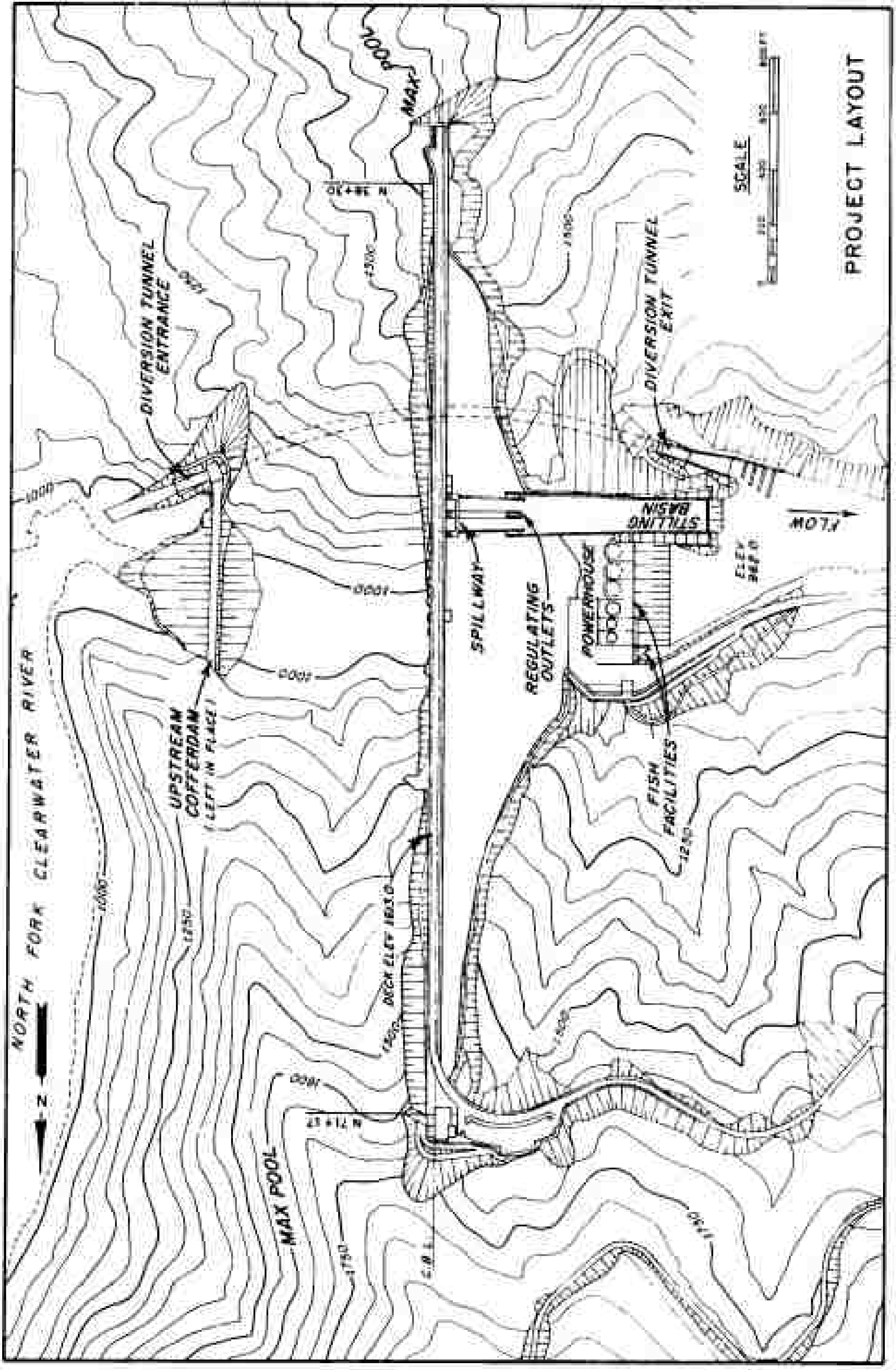
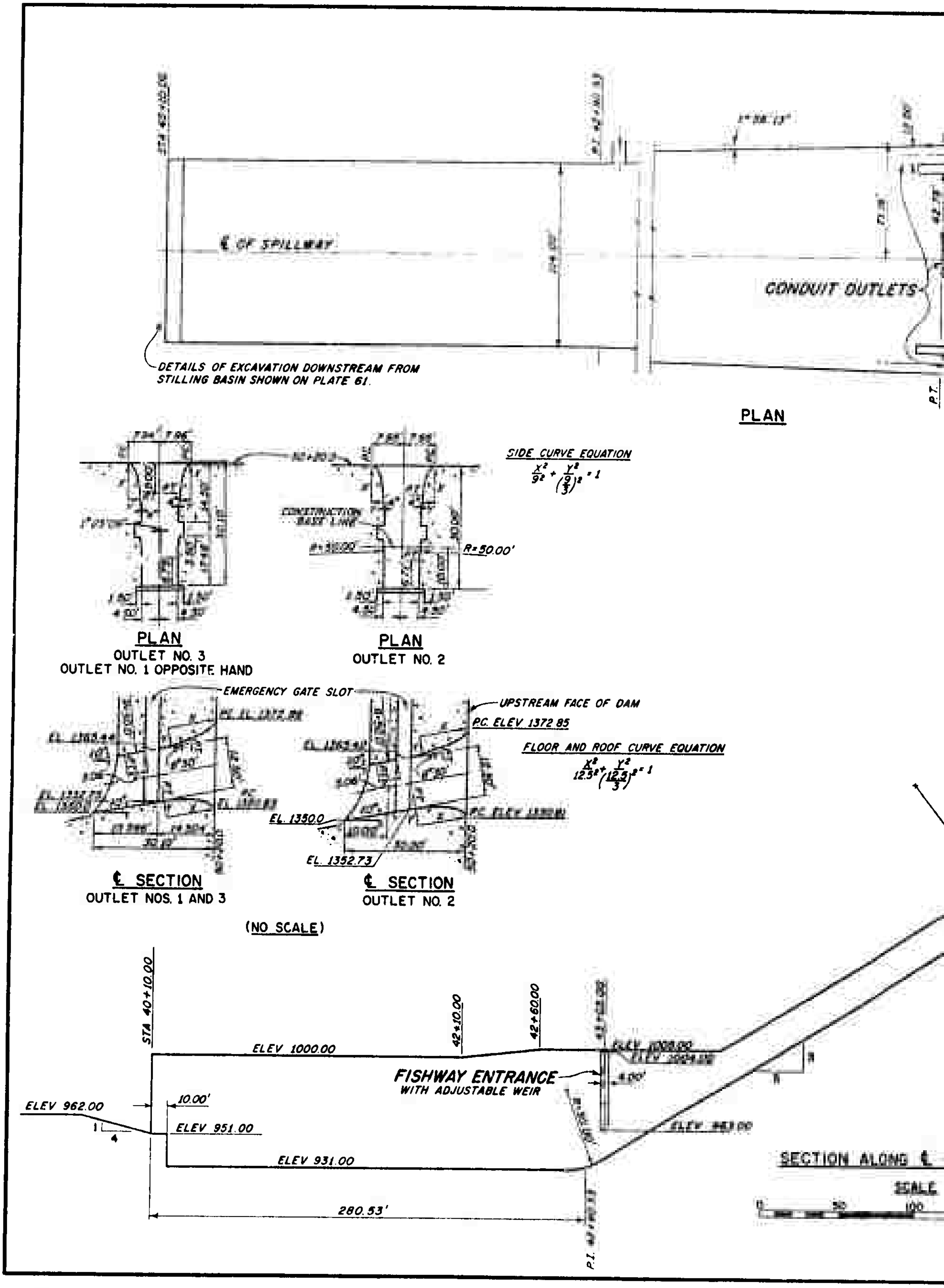

PROJECT LAYOUT
SCALE
NORTH FORK CLEARWATER RIVER
N
DIVERSION TUNNEL ENTRANCE
UPSTREAM COFFERDAM (LEFT IN PLACE)
MAX POOL
MAX POOL
SPILLWAY
REGULATING OUTLETS
POWERHOUSE
STILLING BASIN
FLOW
FISH FACILITIES
DIVERSION TUNNEL EXIT

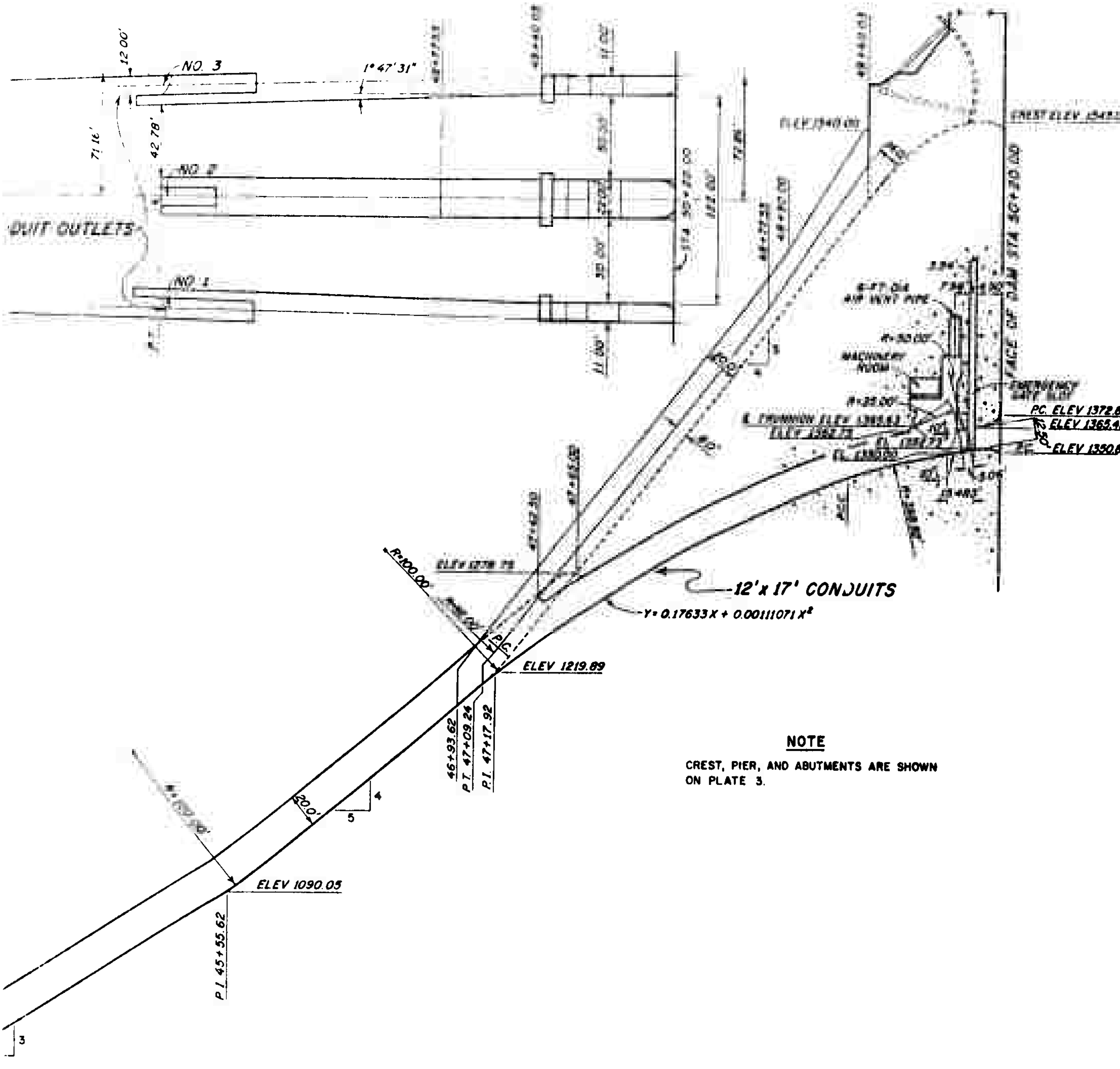
PLATE I



STA 40+10.00
℄ OF SPILLWAY
CONDUIT OUTLETS
DETAILS OF EXCAVATION DOWNSTREAM FROM STILLING BASIN SHOWN ON PLATE 61.
PLAN
SIDE CURVE EQUATION
CONSTRUCTION BASE LINE
R=50.00'
PLAN
OUTLET NO. 3
OUTLET NO. 1 OPPOSITE HAND
PLAN
OUTLET NO. 2
EMERGENCY GATE SLOT
UPSTREAM FACE OF DAM
PC ELEV 1372.85
FLOOR AND ROOF CURVE EQUATION
EL. 1350.0
EL. 1352.73
℄ SECTION
OUTLET NOS. 1 AND 3
℄ SECTION
OUTLET NO. 2
(NO SCALE)
STA 40+10.00
42+10.00
42+60.00
ELEV 1000.00
FISHWAY ENTRANCE
WITH ADJUSTABLE WEIR
ELEV 962.00
10.00'
ELEV 951.00
ELEV 931.00
280.53'
SECTION ALONG ℄
SCALE

PLATE 2

① YC



NOTE

CREST, PIER, AND ABUTMENTS ARE SHOWN ON PLATE 3.

ECTION ALONG ℄ OF SPILLWAY

SCALE

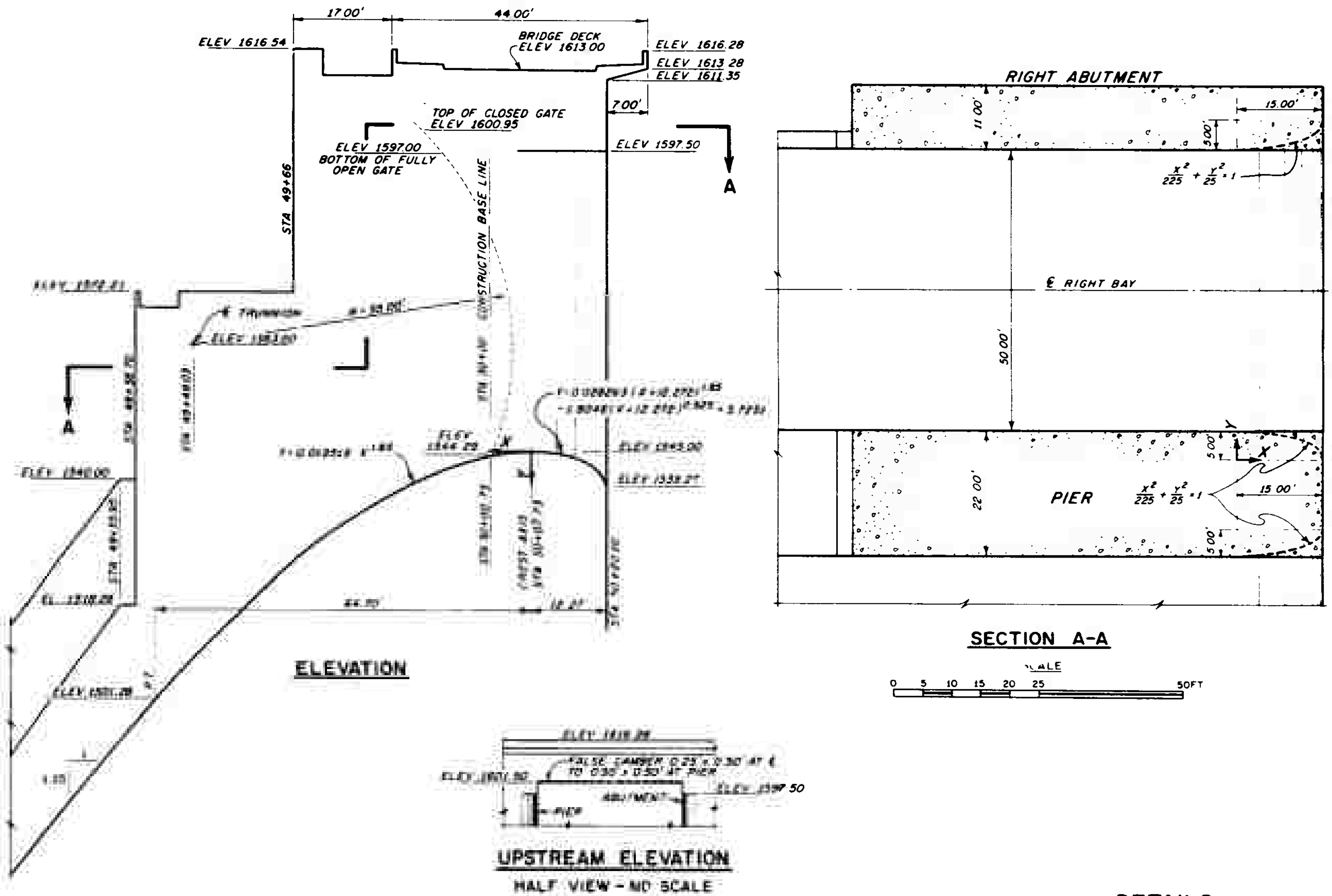
50 100 200 FT

PLAN, SECTION, AND DETAILS

SPILLWAY CHUTE, OUTLET CONDUITS, AND STILLING BASIN

PLATE

2 of 7



DETAILS

SPILLWAY CREST, PIER, AND ABUTMENTS

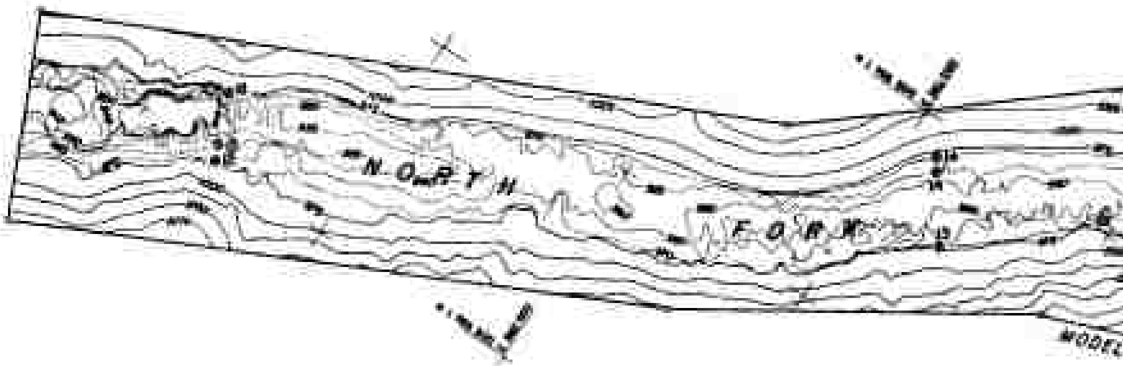
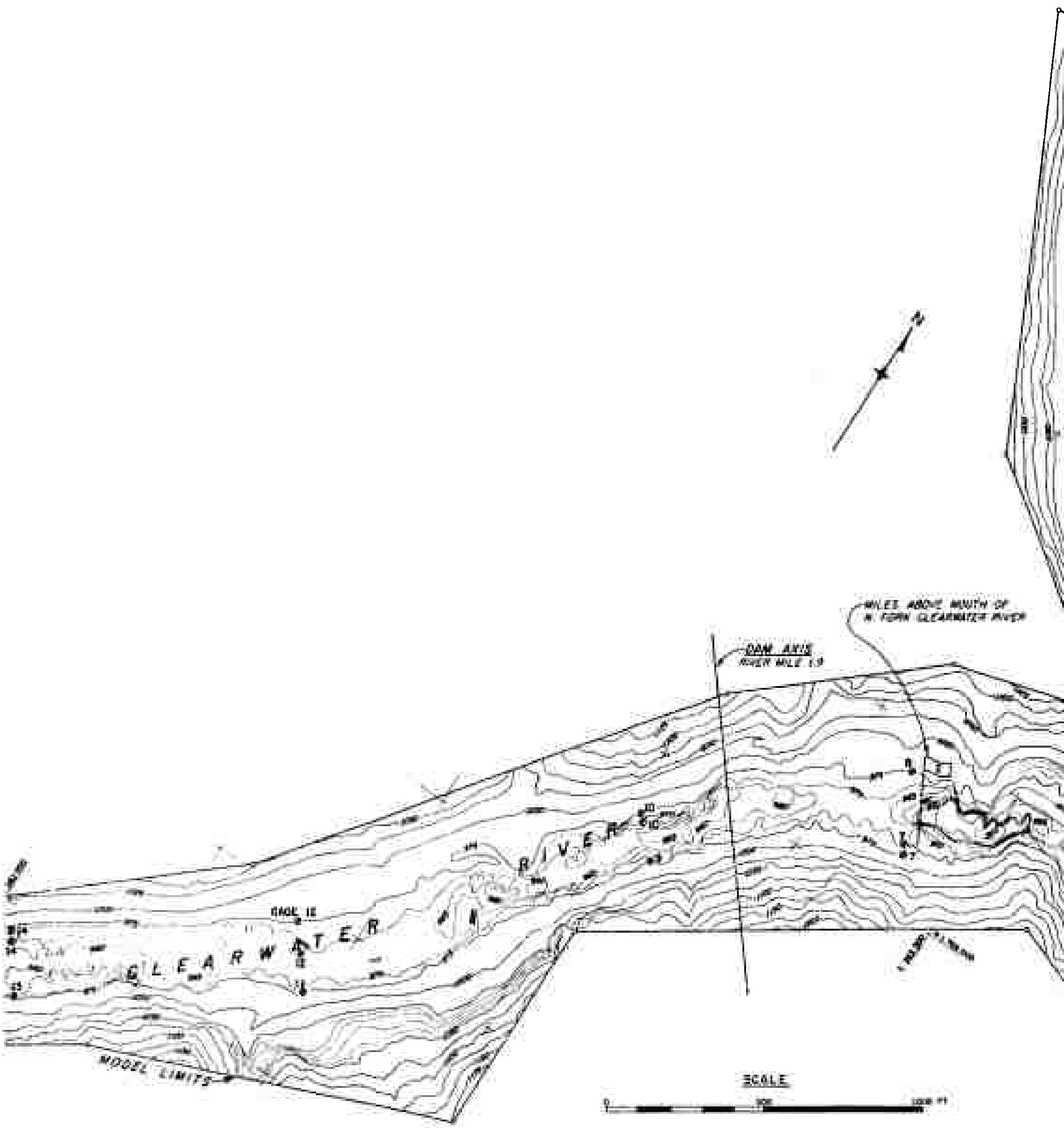
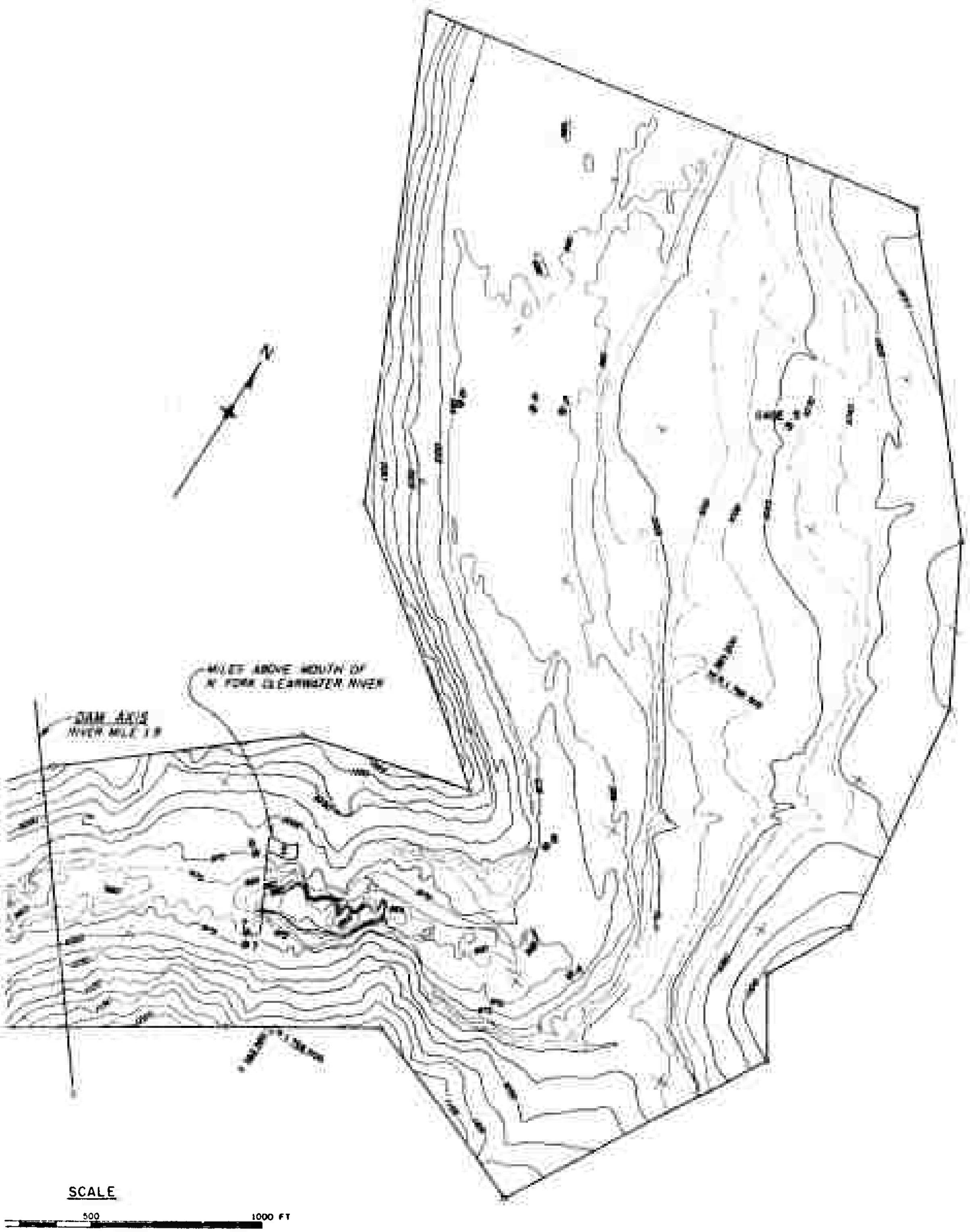


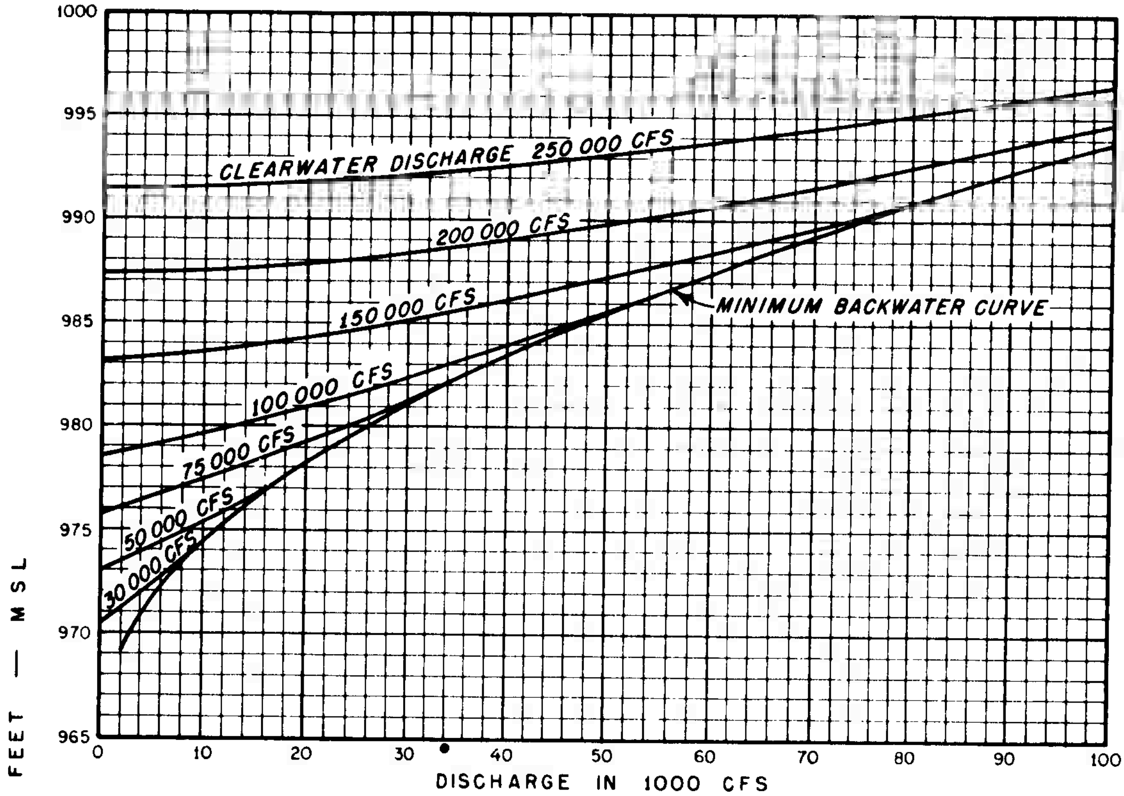
Plate 4

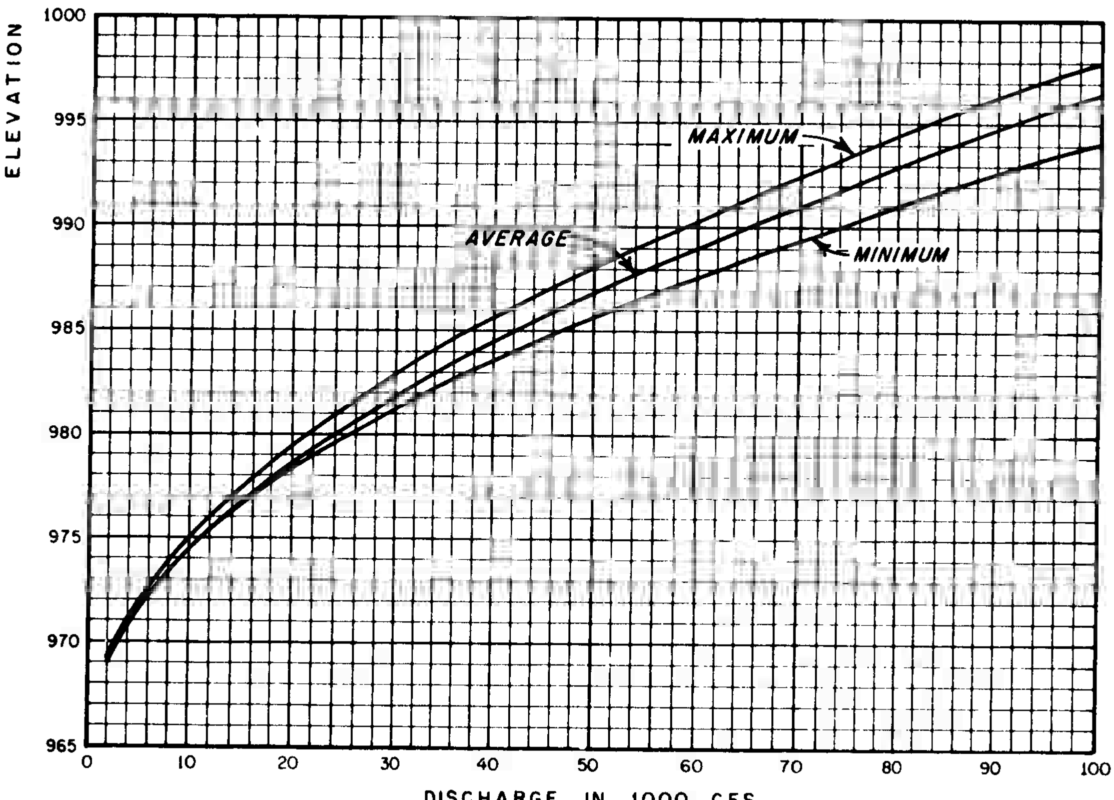

MILES ABOVE MOUTH OF
N. FORK CLEARWATER RIVER
DAM AXIS
RIVER MILE 1.9
CLEARWATER RIVER
GAGE 12
MODEL LIMITS
SCALE



MODEL LAYOUT

PLATE 4

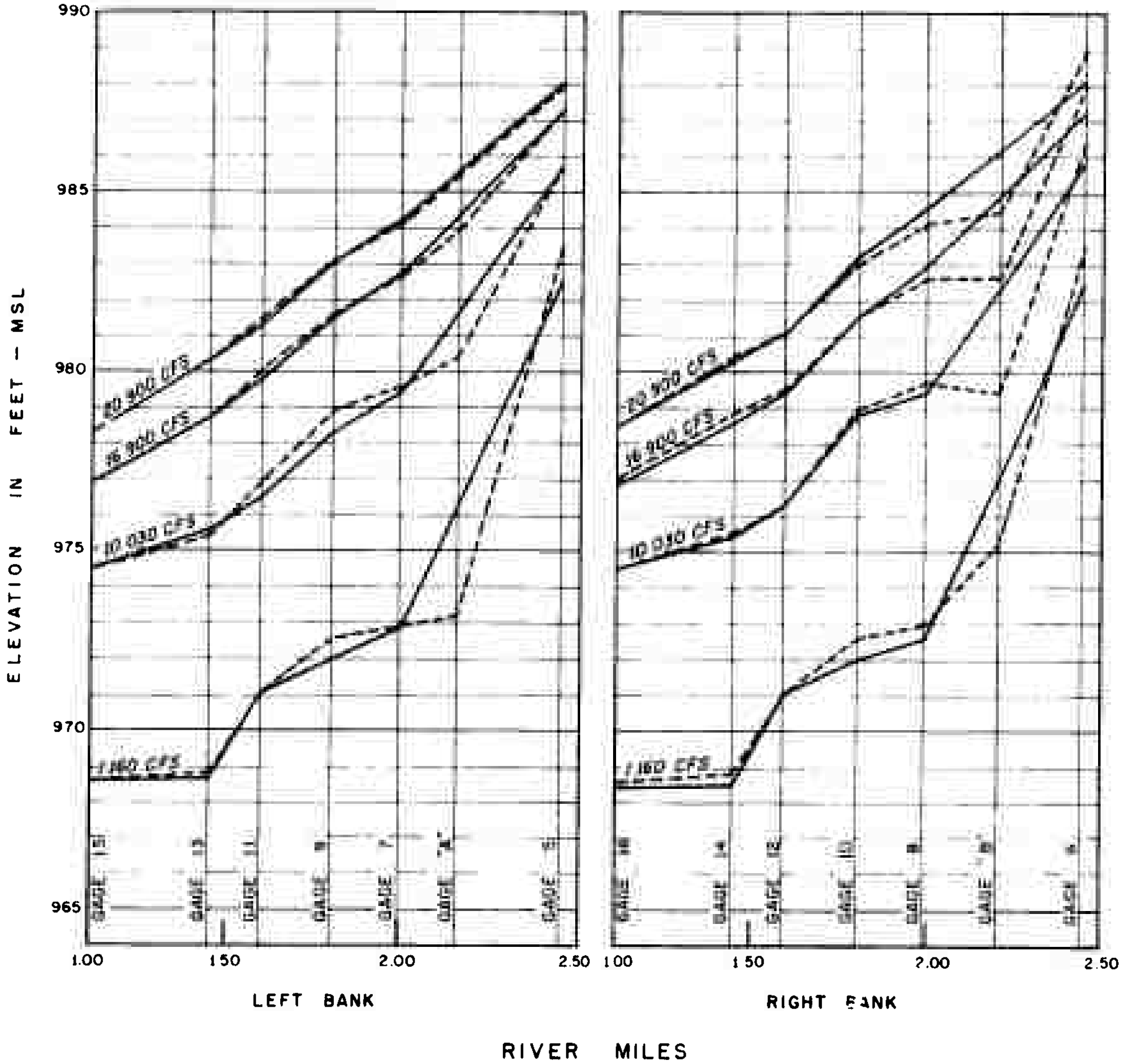




NOTES

1. CURVES SHOW MAXIMUM, AVERAGE AND MINIMUM BACKWATER EFFECTS OF FLOW IN CLEARWATER RIVER BELOW MOUTH OF NORTH FORK.
2. GAGE LOCATION SHOWN ON PLATE 4.

RATING CURVE
NORTH FORK CLEARWATER RIVER
RIVER MILE 1.10, NATURAL CHANNEL



LEGEND

——————— PROTOTYPE
- - - - - - - MODEL

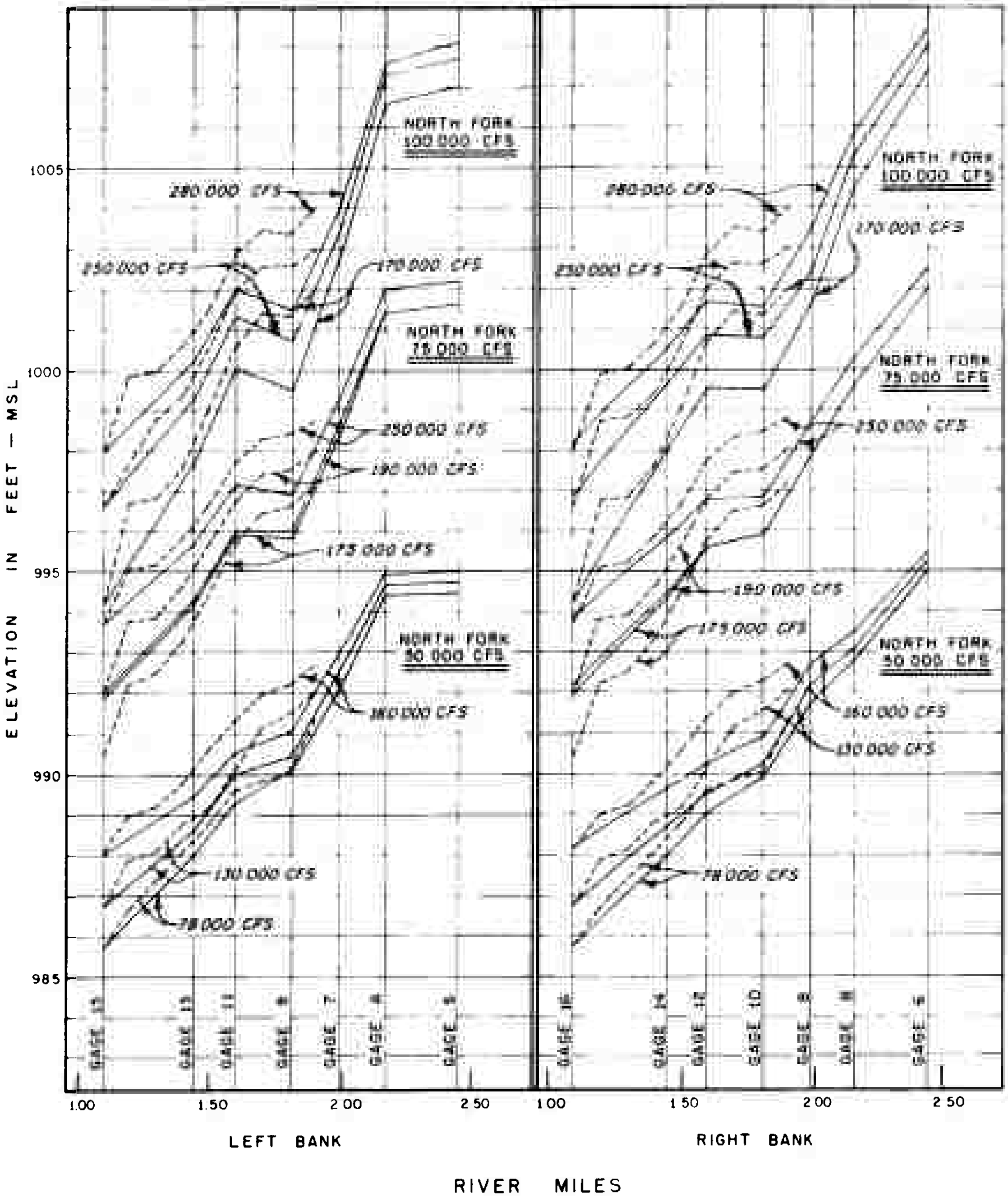
NOTES

1. GAGE LOCATIONS SHOWN ON PLATE 4
2. RIVER MILES ALONG NORTH FORK

VERIFICATION

WATER-SURFACE PROFILES

1160 TO 20,900 CFS IN NORTH FORK



LEGEND

- - - - - - - - - COMPUTED PROFILES
———————— MODEL PROFILES

NOTES

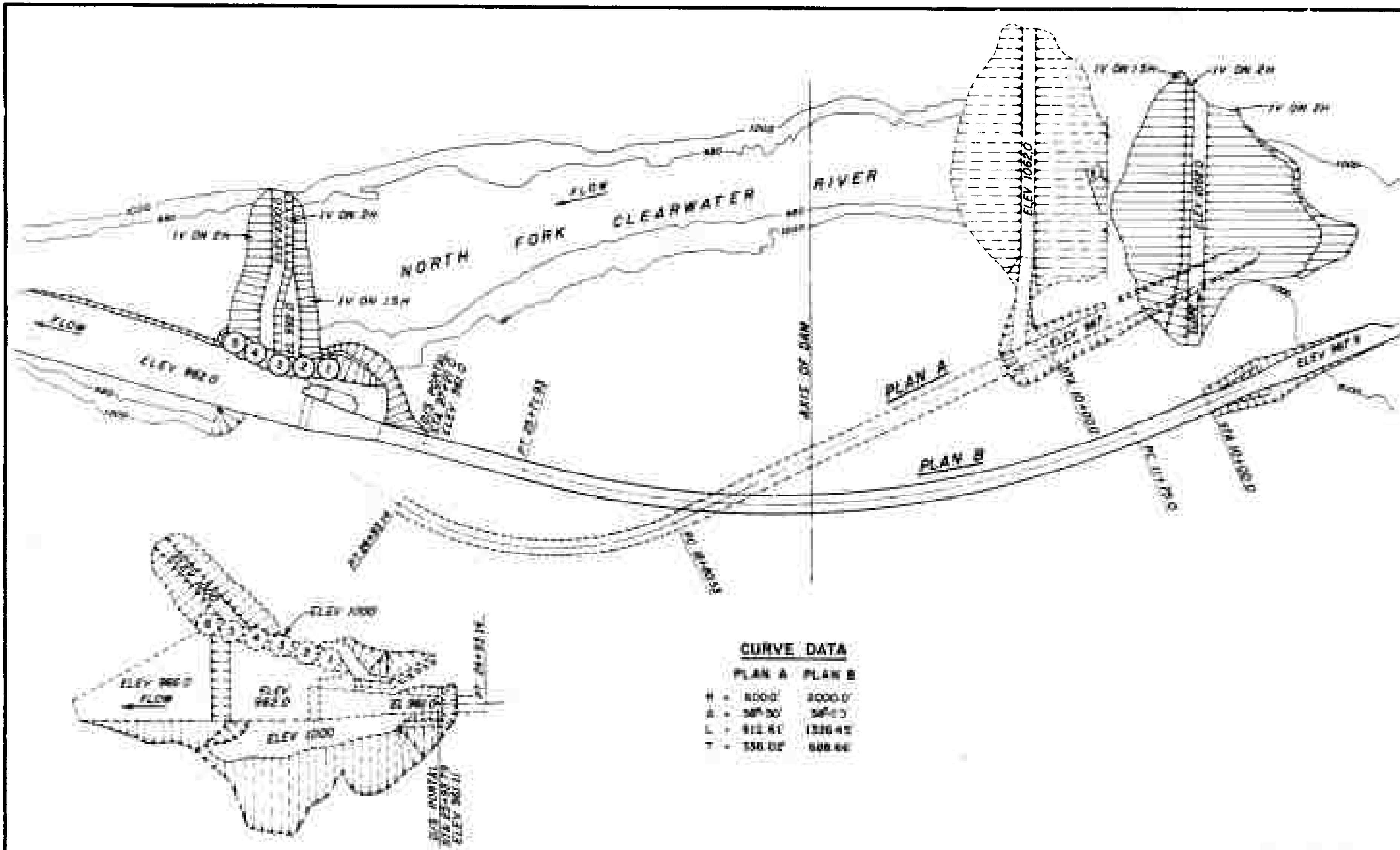
1 GAGE LOCATIONS SHOWN ON PLATE 4
2 RIVER MILES ALONG NORTH FORK

VERIFICATION

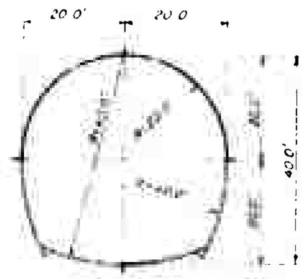
WATER-SURFACE PROFILES

50 000 TO 100 000 CFS IN NORTH FORK

78 000 TO 280 000 CFS IN CLEARWATER RIVER



PLANS A AND B DIVERSION TUNNEL



TYPICAL PIEZOMETER RING

STATION 10+61 TO 25+90

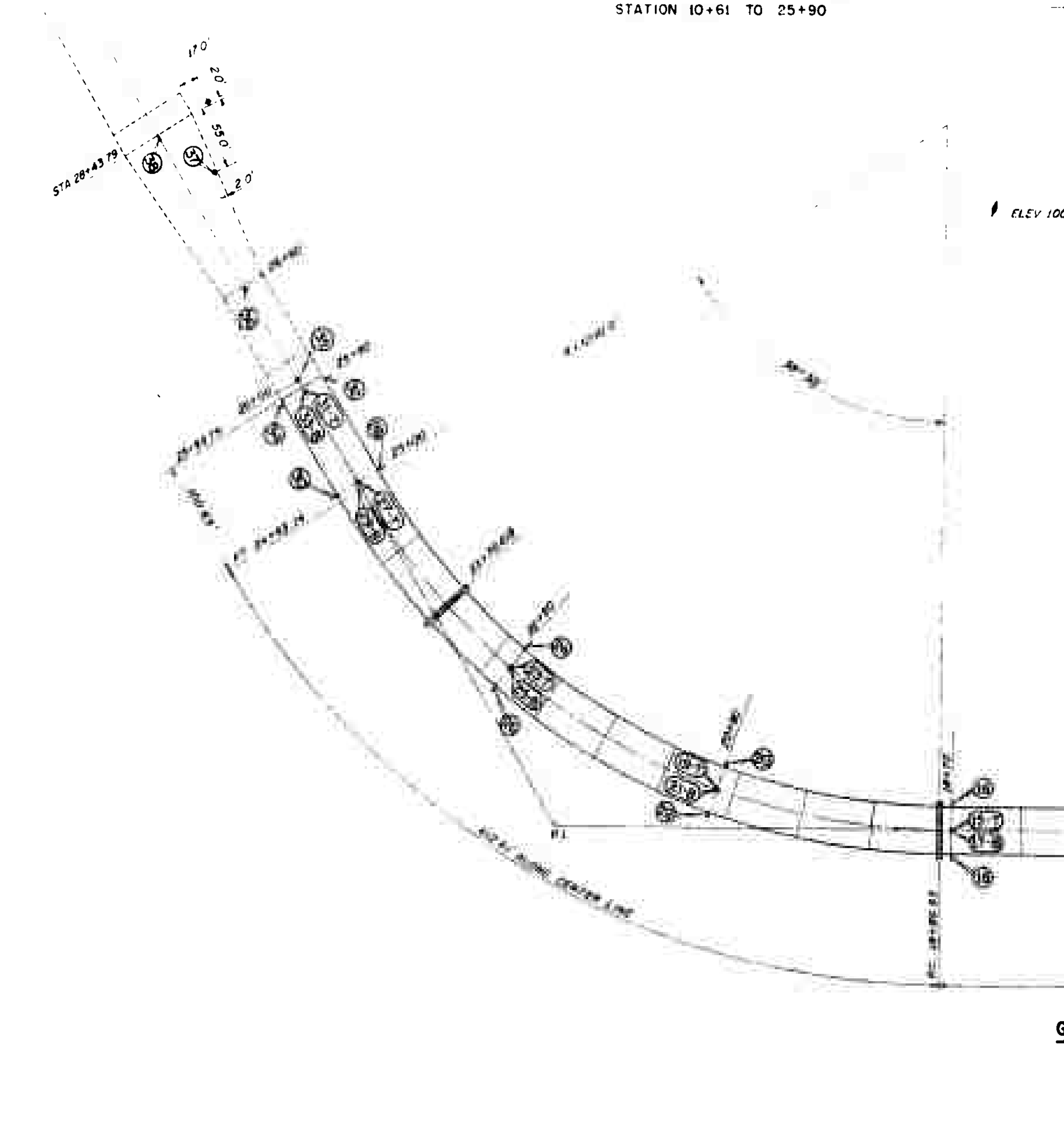
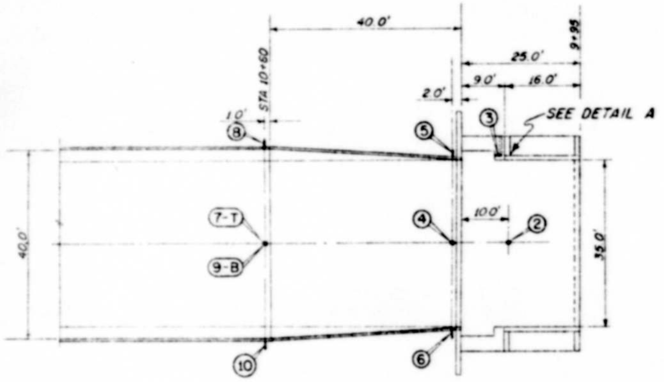
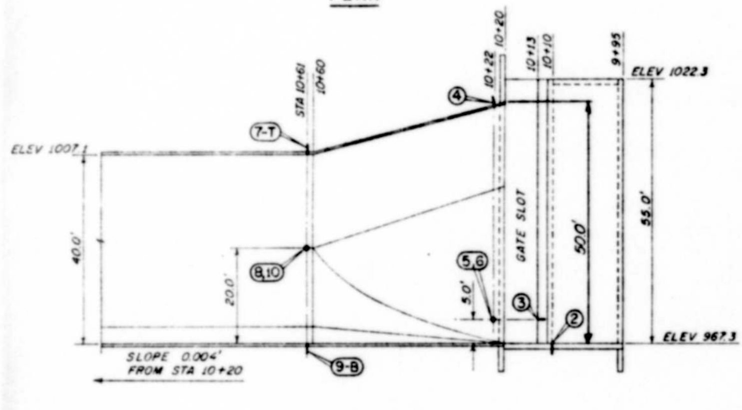


PLATE 9



PLAN

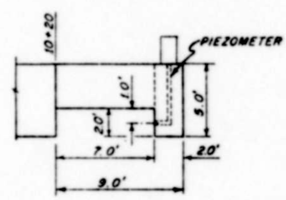


ELEVATION

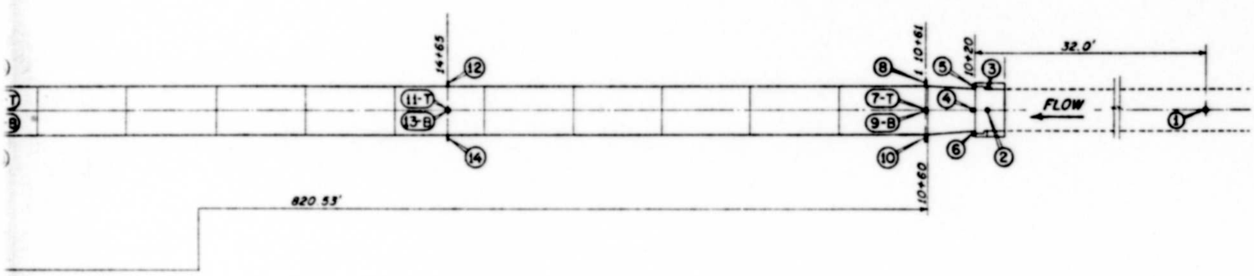
ENTRANCE TRANSITION

PIEZOMETER LOCATIONS

PIEZOMETER NO	STATION	ELEVATION
1	9+88	967.3
2	10+10	967.3
3	10+13	972.3
4	10+22	1016.8
5	10+22	972.3
6	10+22	972.3
7	10+61	1007.1
8	10+61	987.1
9	10+61	987.1
10	10+61	967.1
11	14+65	1005.5
12	14+65	985.5
13	14+65	965.5
14	14+65	985.5
15	18+70	1003.9
16	18+70	983.9
17	18+70	963.9
18	18+70	983.9
19	20+80	1003.1
20	20+80	983.1
21	20+80	963.1
22	20+80	983.1
23	22+90	1002.2
24	22+90	982.2
25	22+90	962.2
26	22+90	982.2
27	25+00	1001.4
28	25+00	981.4
29	25+00	961.4
30	25+00	981.4
31	25+90	1001.0
32	25+90	981.0
33	25+90	961.0
34	25+90	981.0
35	26+00	961.0
36	26+90	961.0
37	27+88	969.2
38	28+43.8	973.5
39	28+45	962.0



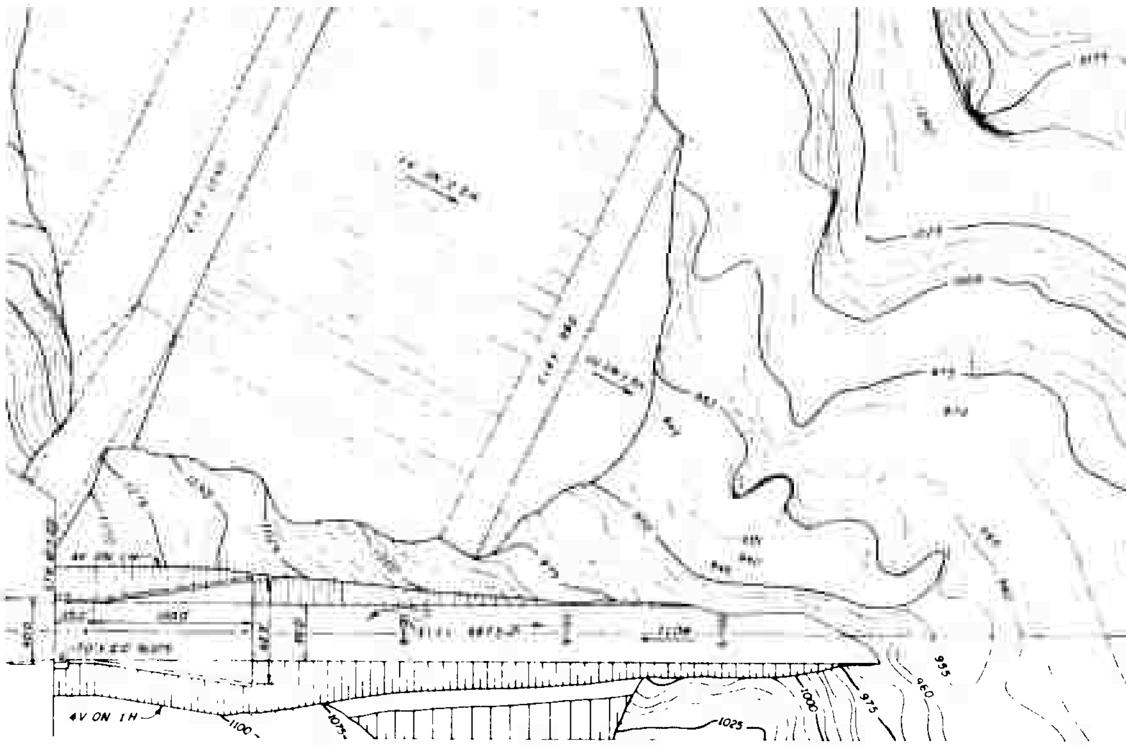
DETAIL A



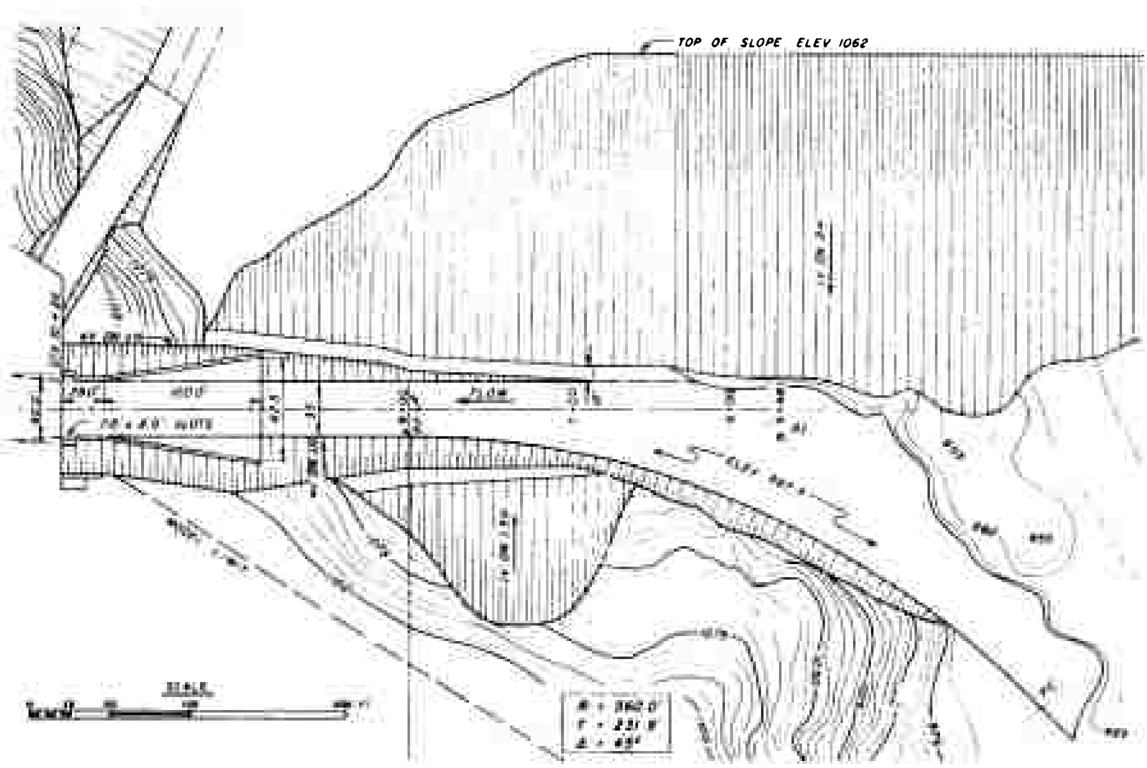
GENERAL PLAN

DIVERSION TUNNEL LAYOUT AND PIEZOMETER LOCATIONS

PLAN A – ORIGINAL DESIGN



PLAN A



PLAN B

NOTE

TUNNEL LAYOUT IS SHOWN ON PLATE 8

ENTRANCE PLANS A AND B

PLAN A DIVERSION TUNNEL

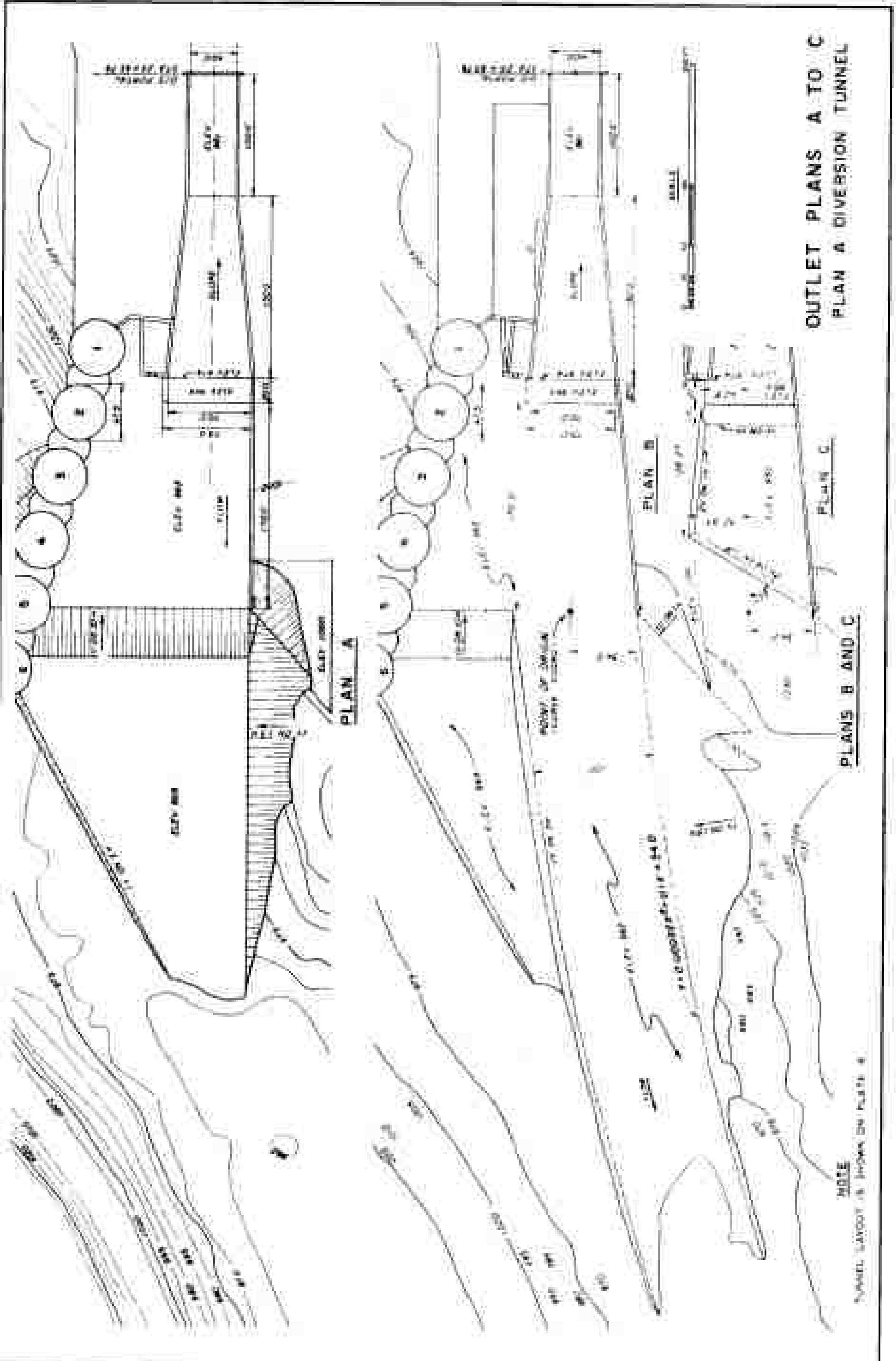
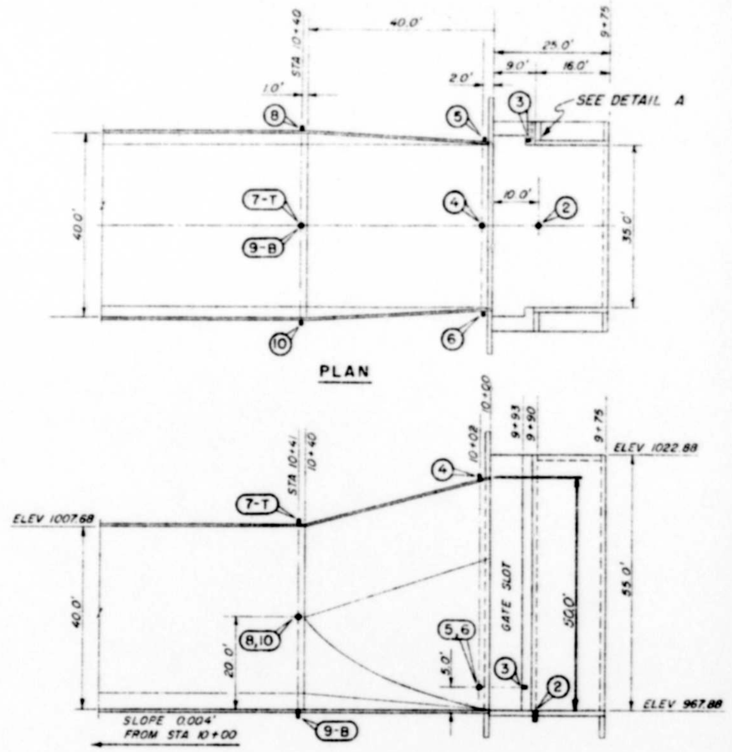

OUTLET PLANS A TO C
PLAN A DIVERSION TUNNEL
PLAN A
PLAN B
PLAN C
PLANS B AND C
NOTE

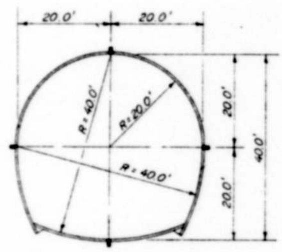
PLATE 11

PIEZOMETER LOCATIONS

PIEZOMETER NO	STATION	ELEVATION
1	6+75	967.9
2	9+90	967.9
3	9+93	972.9
4	10+02	1017.9
5	10+02	972.9
6	10+02	972.9
7	10+41	1007.7
8	10+41	987.7
9	10+41	967.7
10	10+41	987.7
27	26+26.75	1001.4
28	26+26.75	981.4
29	26+26.75	961.4
30	26+26.75	981.4
31	27+17.21	1001.0
32	27+17.21	981.0
33	27+17.21	961.0
34	27+17.21	981.0
35	27+27.21	961.0
36	28+17.21	961.0
37	29+16.45	969.3
38	29+71.00	973.5
39	29+72.2	962.0
50	11+69	1007.2
51	11+69	987.2
52	11+69	967.2
53	11+69	987.2
54	14+99	1005.9
55	14+99	985.9
56	14+99	965.9
57	14+99	985.9
58	18+29	1004.6
59	18+29	984.6
60	18+29	964.6
61	18+29	984.6
62	21+59	1003.2
63	21+59	983.2
64	21+59	963.2
65	21+59	983.2
66	24+99	1001.9
67	24+99	981.9
68	24+99	961.9
69	24+99	981.9

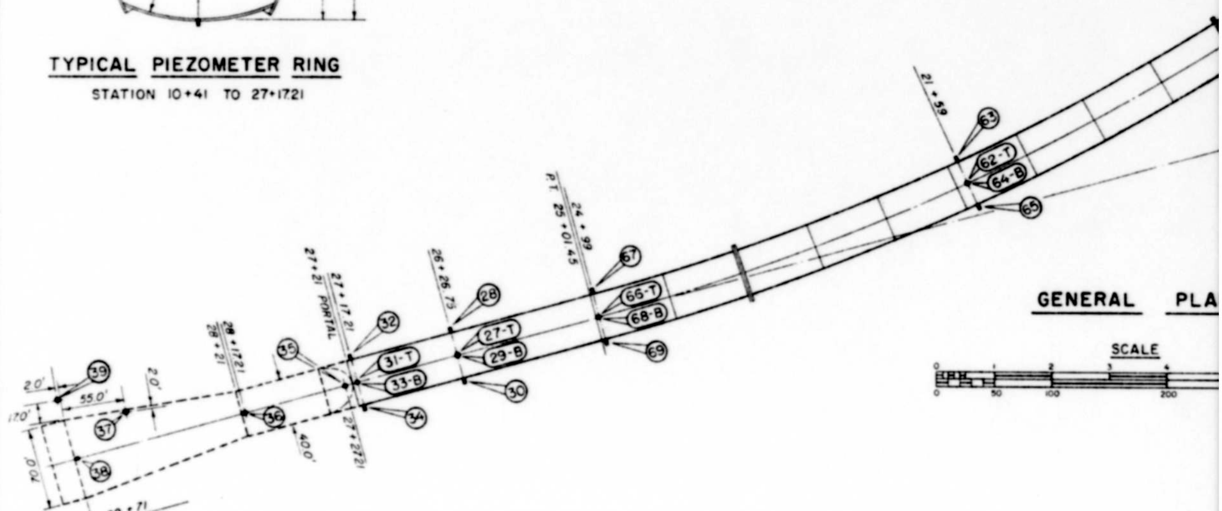


ENTRANCE TRANSITION



TYPICAL PIEZOMETER RING

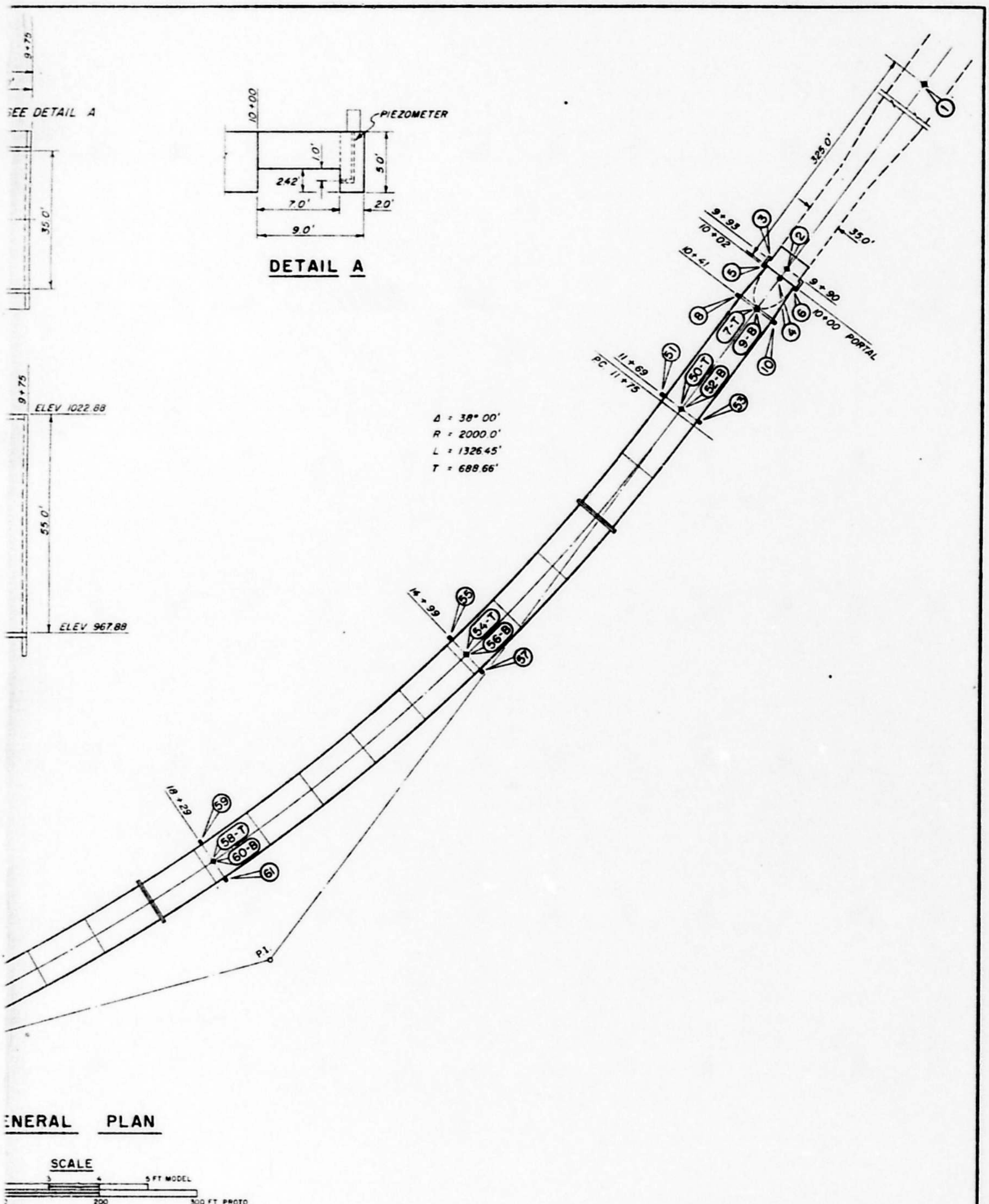
STATION 10+41 TO 27+17.21



GENERAL PLA

PLATE 12

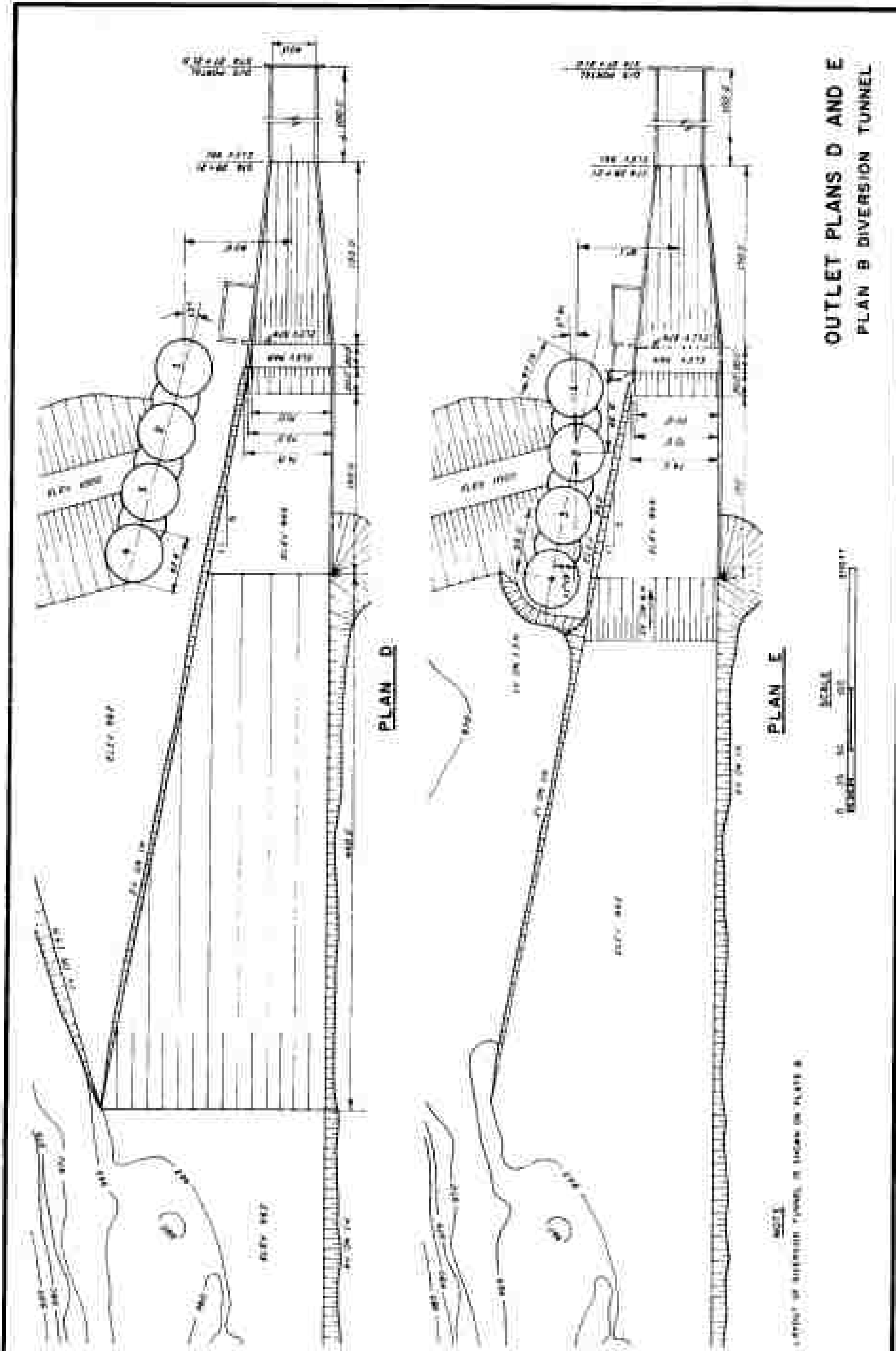
①



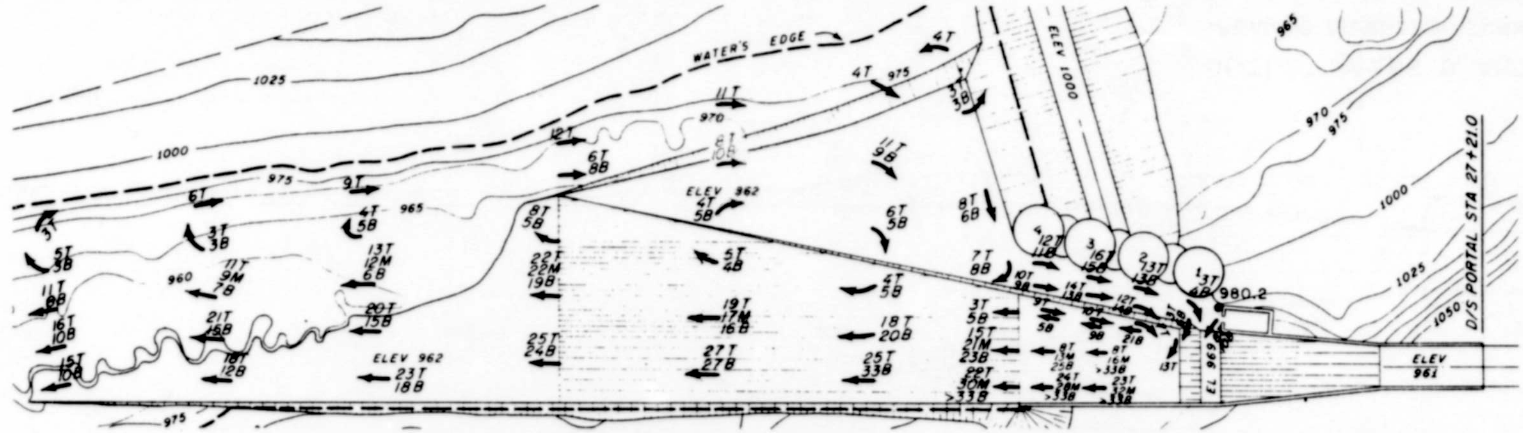
DIVERSION TUNNEL LAYOUT AND PIEZOMETER LOCATIONS

PLAN B — FINAL DESIGN

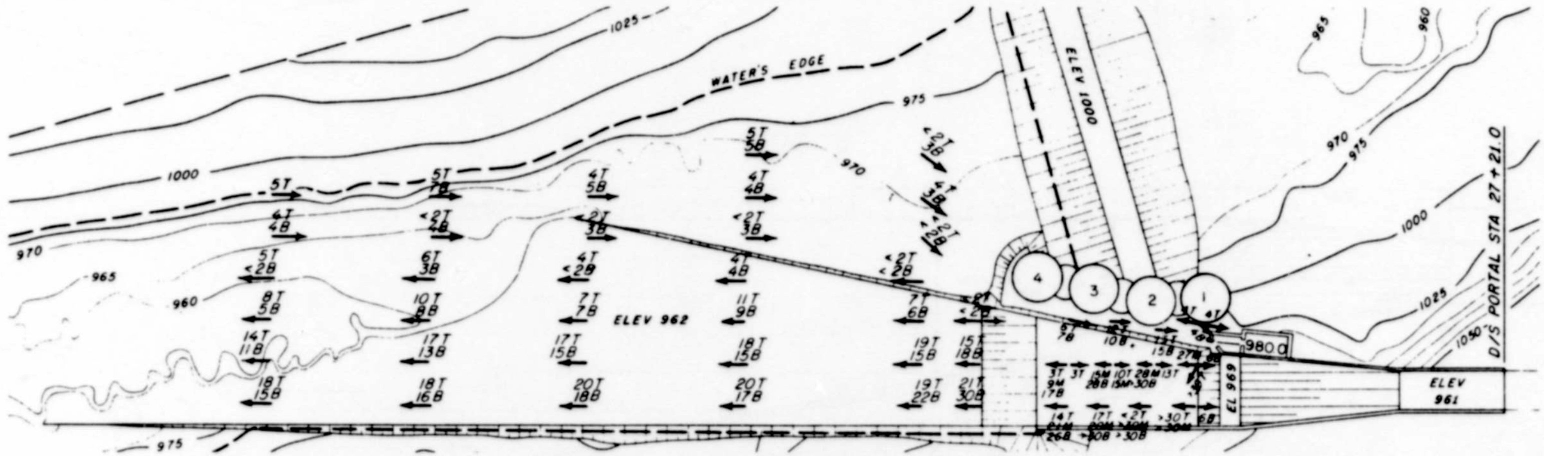
2



OUTLET PLANS D AND E
PLAN B DIVERSION TUNNEL
PLAN D
PLAN E
SCALE



PLAN D



PLAN E

NOTE

OUTLET DETAILS ARE SHOWN ON PLATE 13.

LEGEND

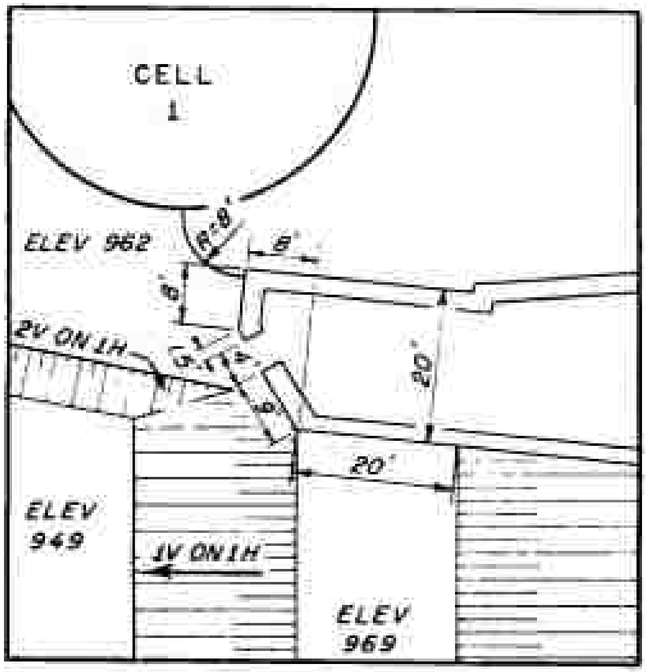
← 4	VELOCITY MEASUREMENTS IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
980.0 ●	WATER-SURFACE ELEVATIONS

FLOW CONDITIONS

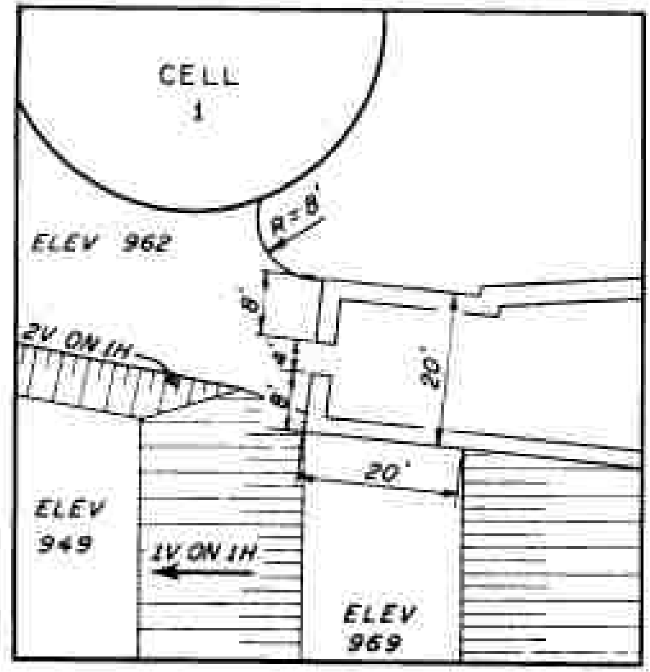
OUTLET PLANS D AND E

PLAN B DIVERSION TUNNEL

RIVER DISCHARGE 30 000 CFS



PLAN E-1



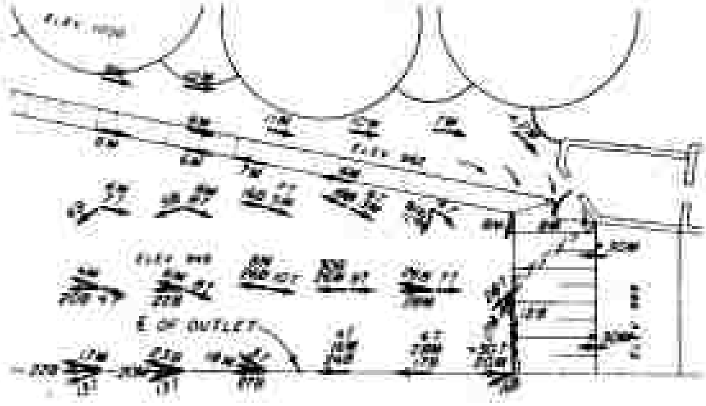
PLAN E-2

NOTE

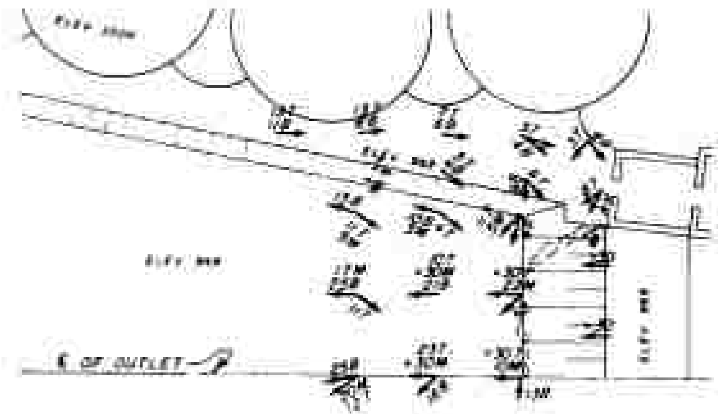
TUNNEL LAYOUT IS SHOWN ON PLATE 8.

FISHWAY ENTRANCE PLANS E-1 AND E-2

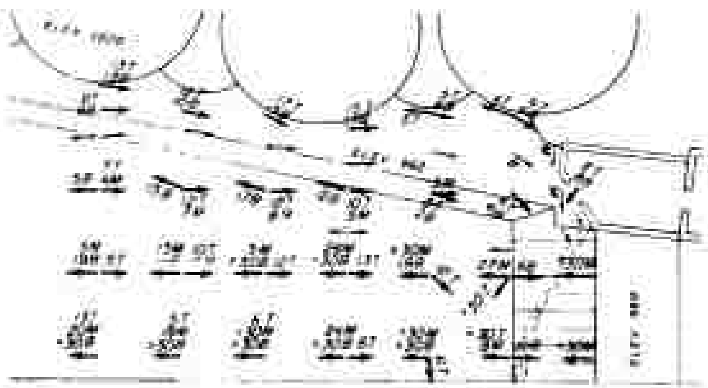
PLAN E OUTLET, PLAN B DIVERSION TUNNEL



RIVER DISCHARGE 20 000 CFS

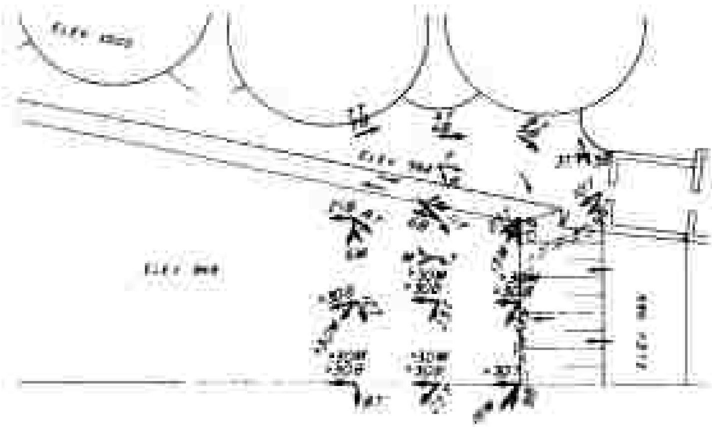


RIVER DISCHARGE 20 000 CFS



RIVER DISCHARGE 30 000 CFS

PLAN E-1



RIVER DISCHARGE 30 000 CFS

PLAN E-2

NOTES

1 ENTRANCE DETAILS ARE SHOWN ON PLATE 15

2 TUNNEL LAYOUT IS SHOWN ON PLATE 8.

LEGEND

4 VELOCITY MEASUREMENTS IN FPS

T 5-FT DEPTH

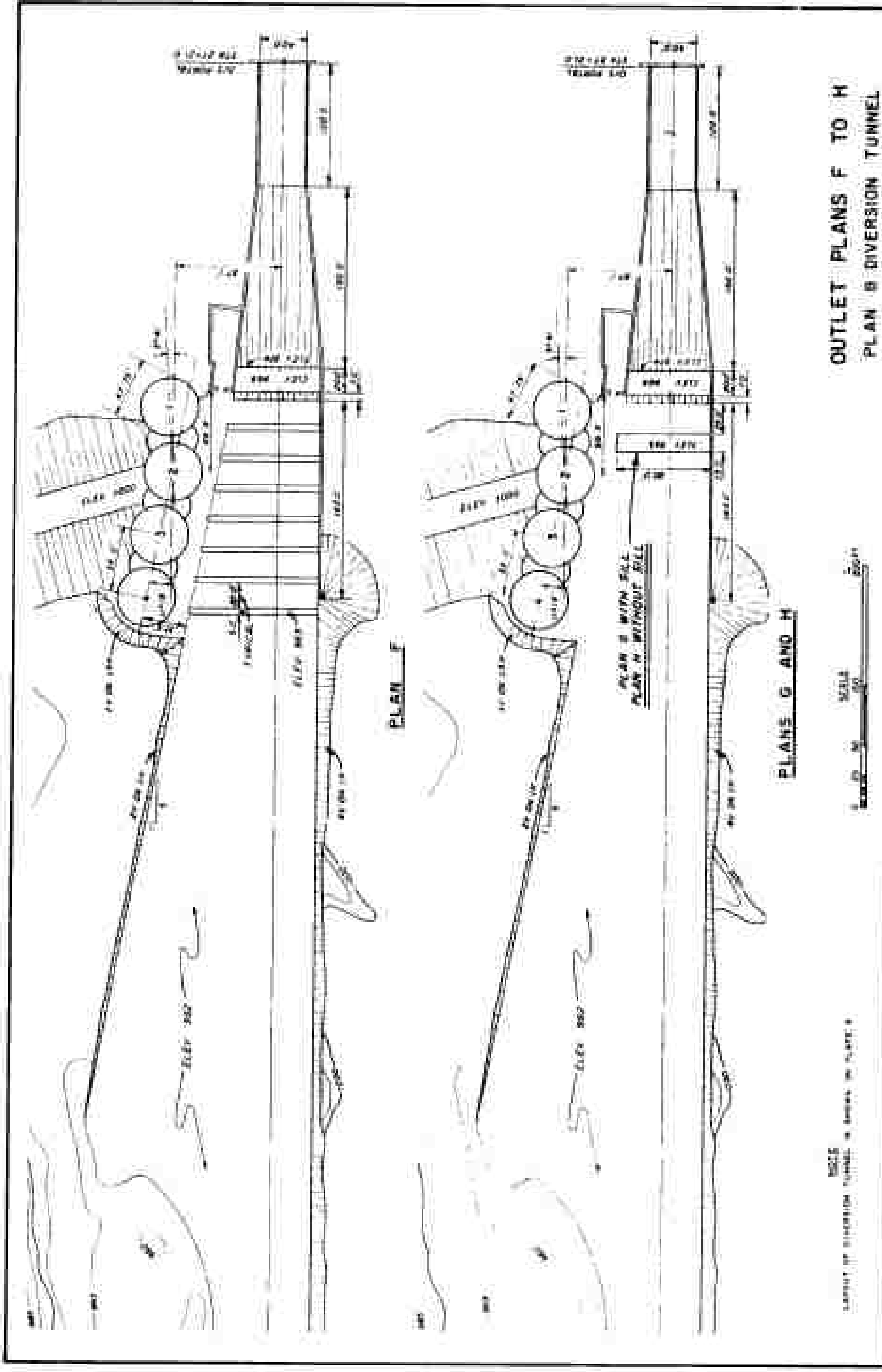
M MID-DEPTH

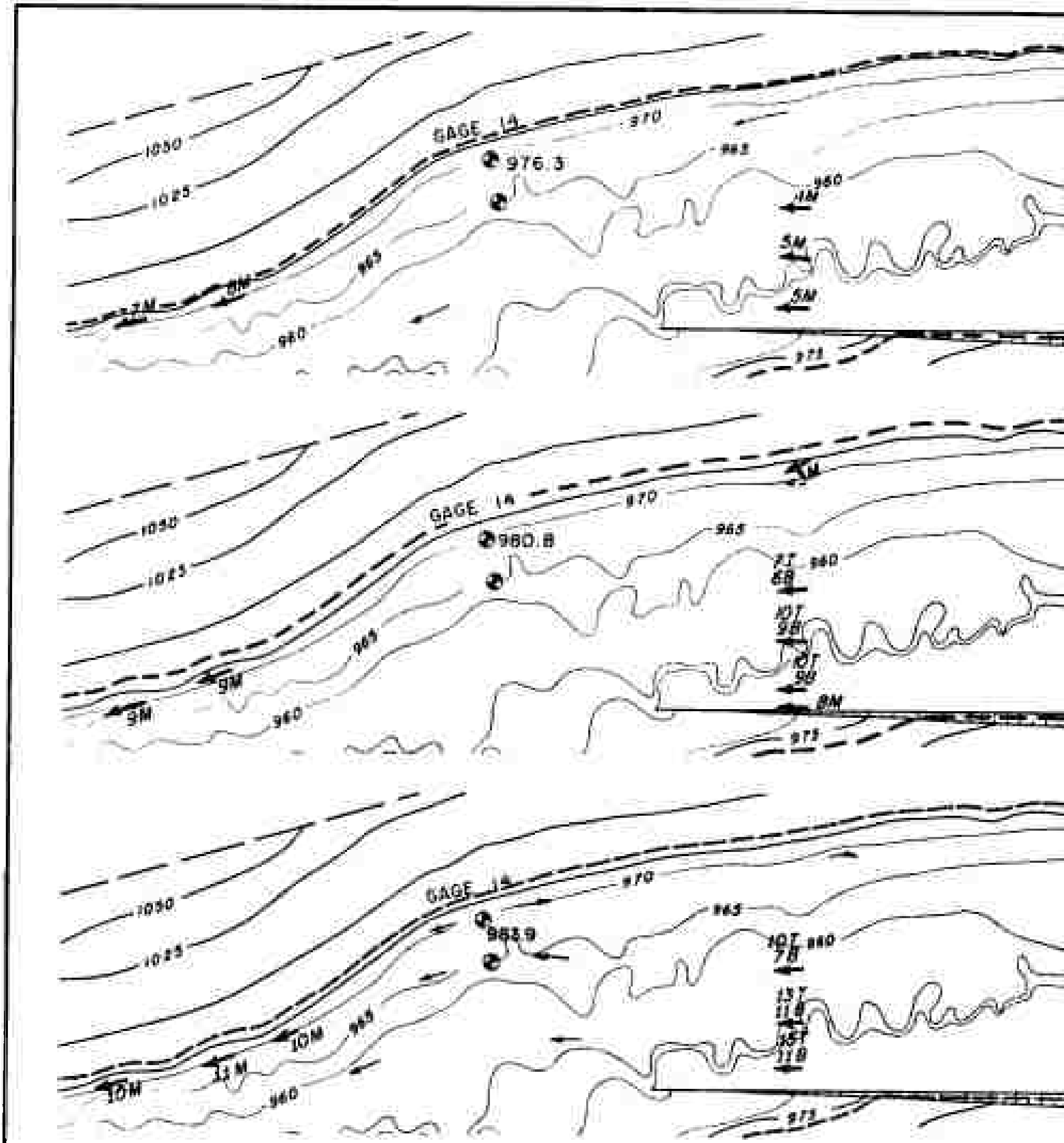
B 5 FT ABOVE BOTTOM

VELOCITIES

FISHWAY ENTRANCE PLANS E-1 AND E-2

PLAN B DIVERSION TUNNEL


OUTLET PLANS F TO H
PLAN 8 DIVERSION TUNNEL
PLAN F
PLANS G AND H
PLAN G WITH SILL
PLAN H WITHOUT SILL
SCALE

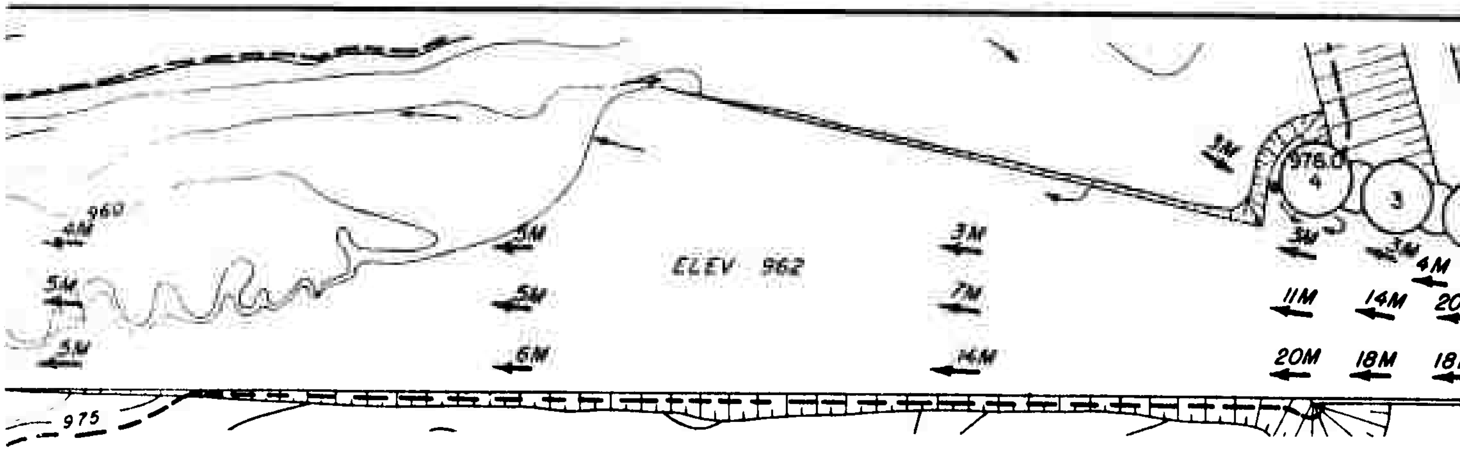


LEGEND

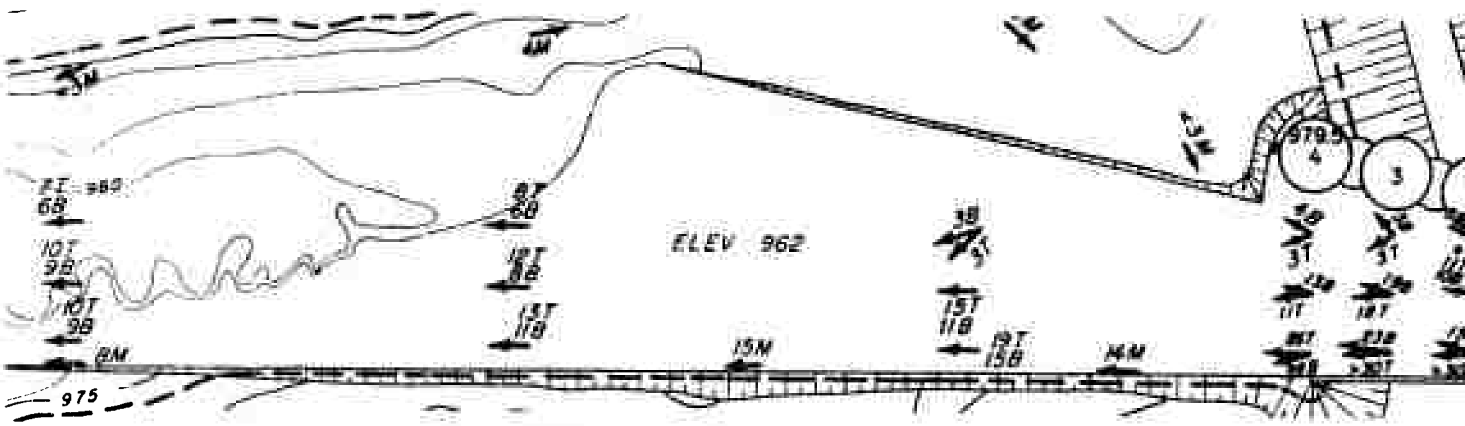
← 4	VELOCITIES MEASUREMENTS IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
983.9 ●	WATER-SURFACE ELEVATIONS

PLATE 18

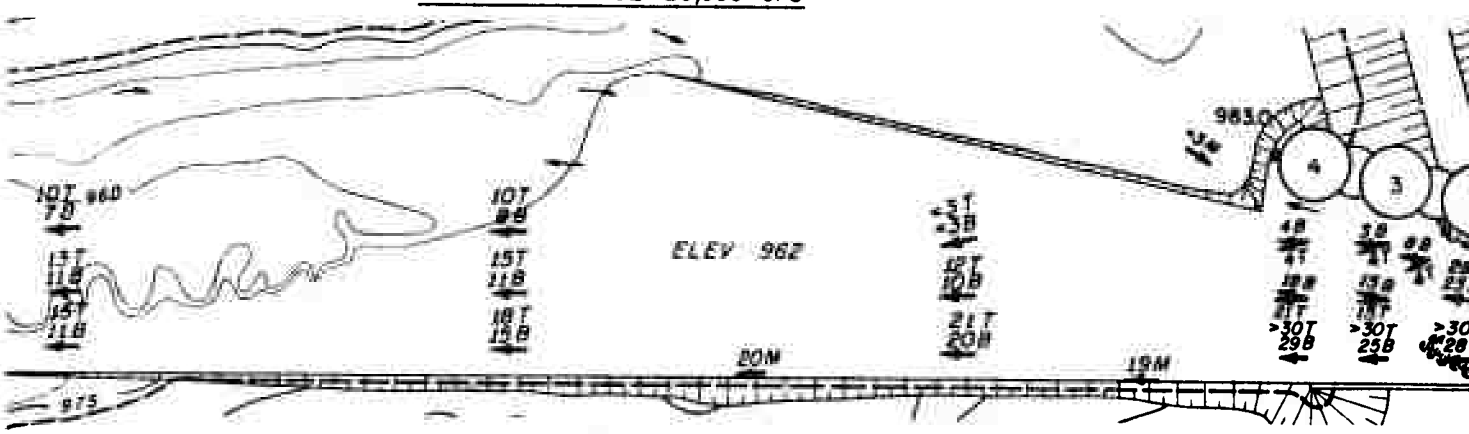
1



RIVER DISCHARGE 10,000 CFS



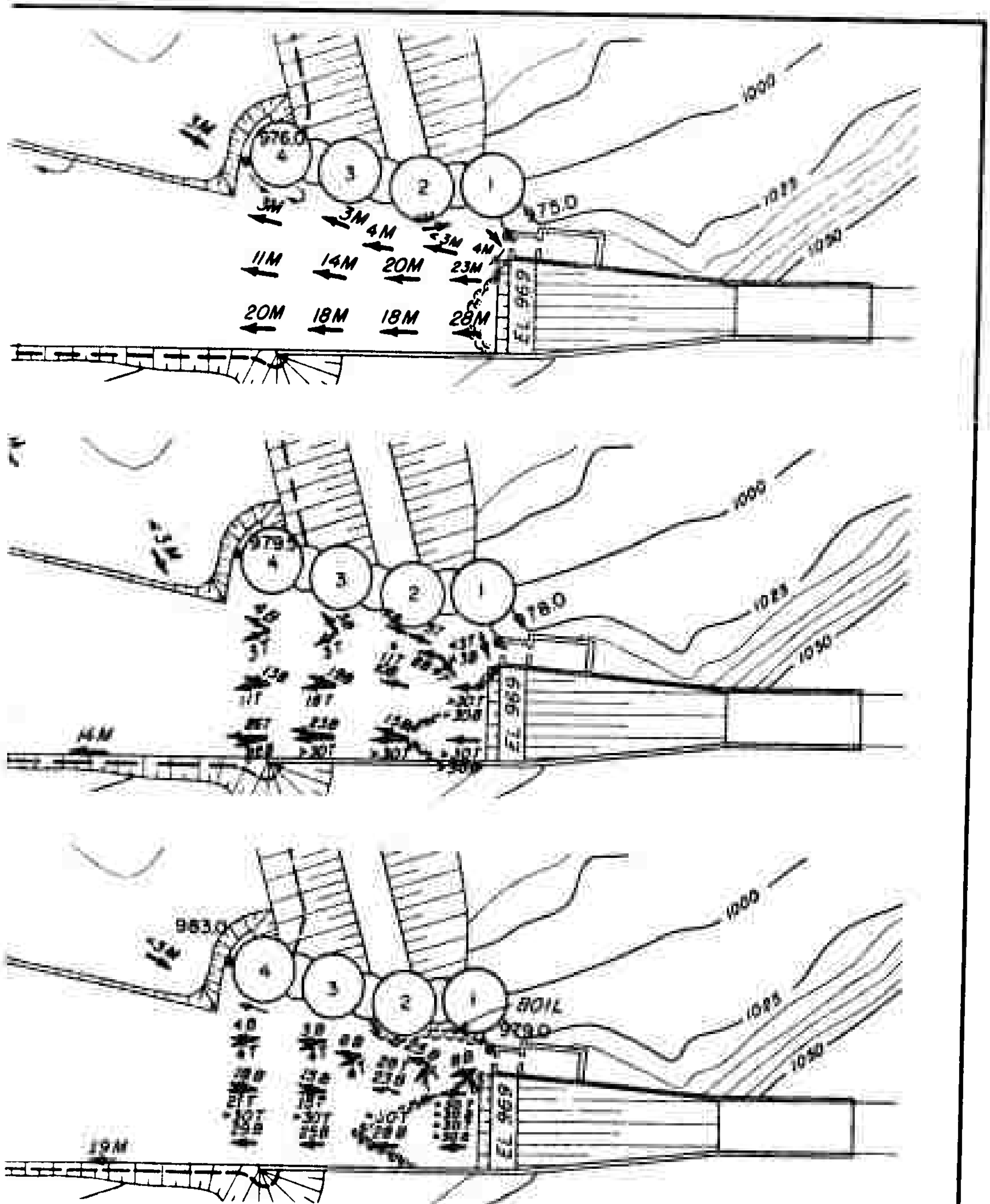
RIVER DISCHARGE 20,000 CFS



RIVER DISCHARGE 30,000 CFS

NOTES

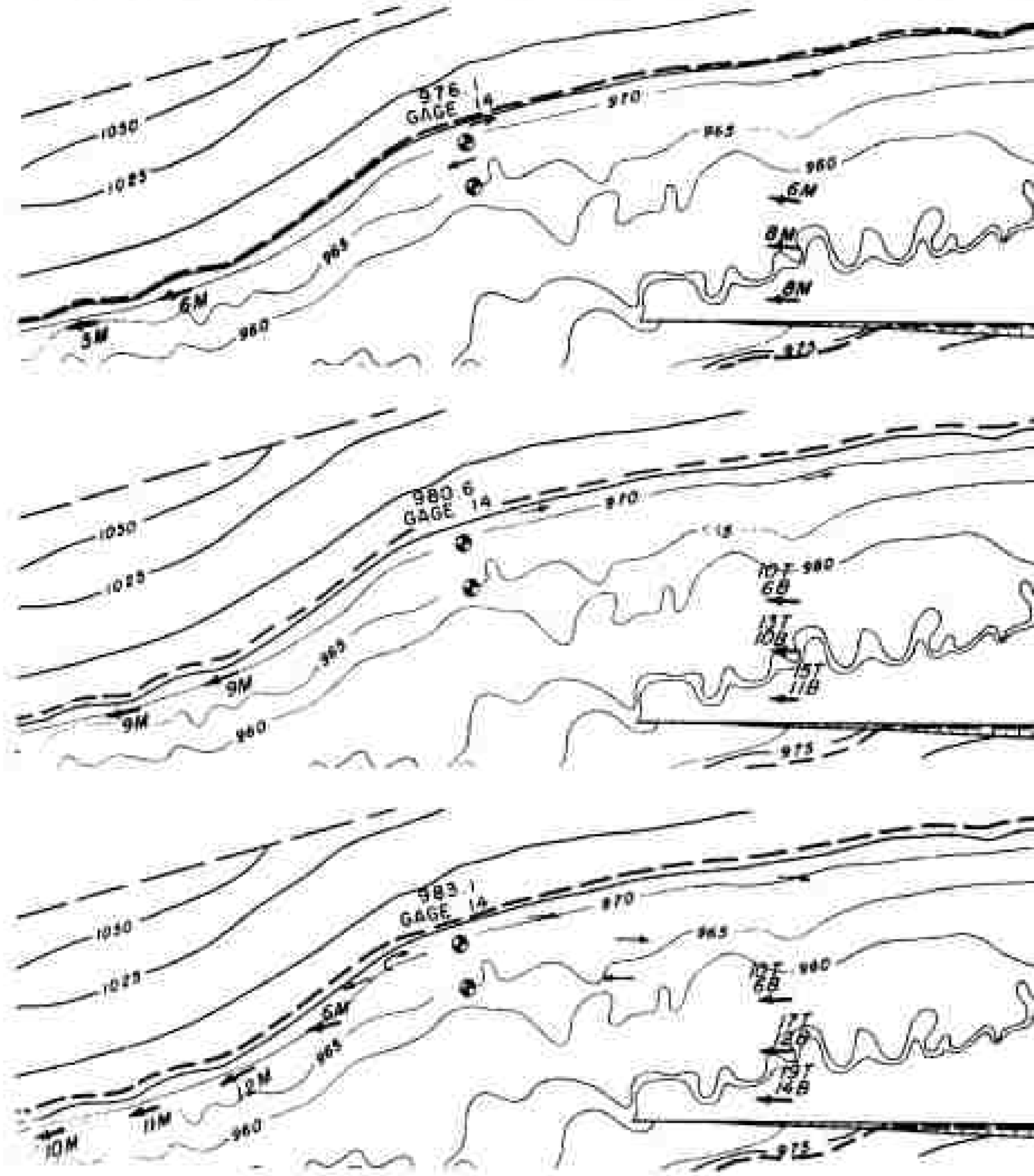
1. OUTLET DETAILS ARE SHOWN ON PLATE 17.
2. SILLS ARE OMITTED FOR CLARITY.



FLOW CONDITIONS

PLAN F OUTLET
PLAN B DIVERSION TUNNEL

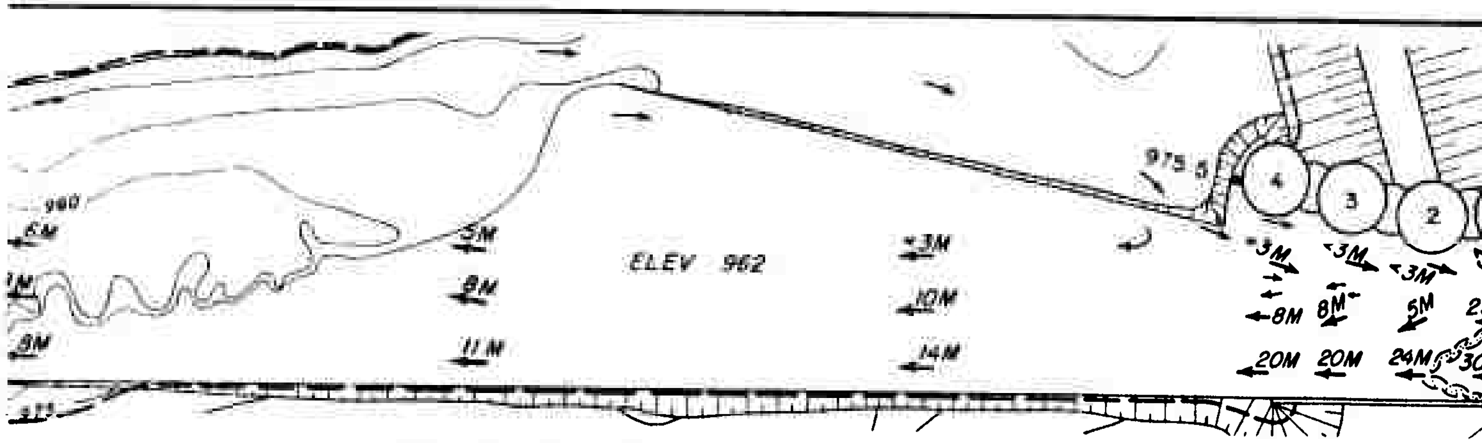
3 of 3



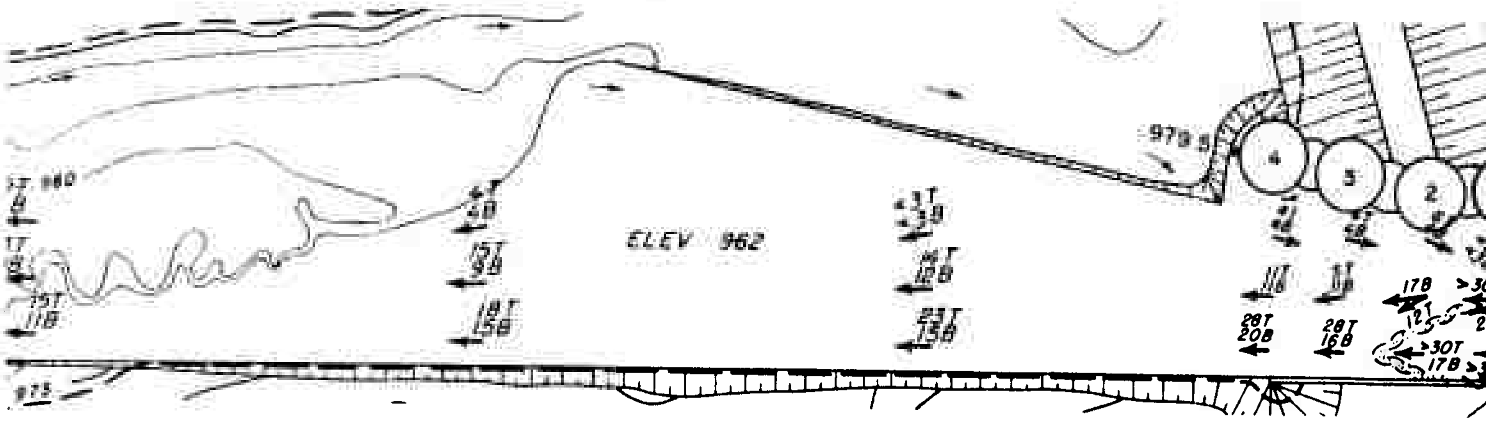
LEGEND

- VELOCITY MEASUREMENTS IN FPS
- T 5-FT DEPTH
- M MID-DEPTH
- B 5 FT ABOVE BOTTOM
- 983.1 ● WATER-SURFACE ELEVATIONS

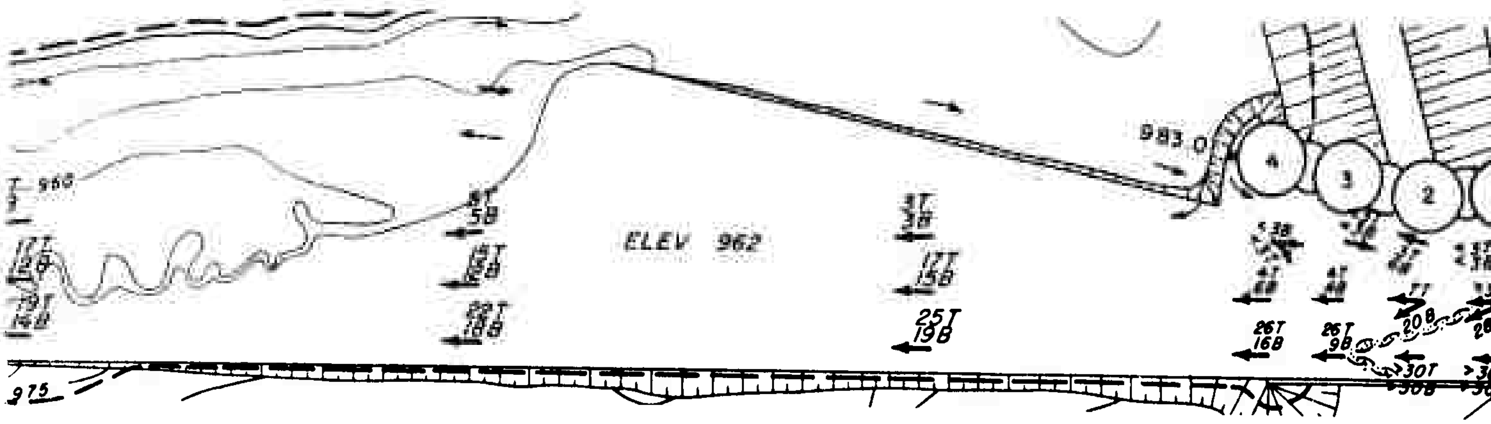
PLATE 19



RIVER DISCHARGE 10,000 CFS



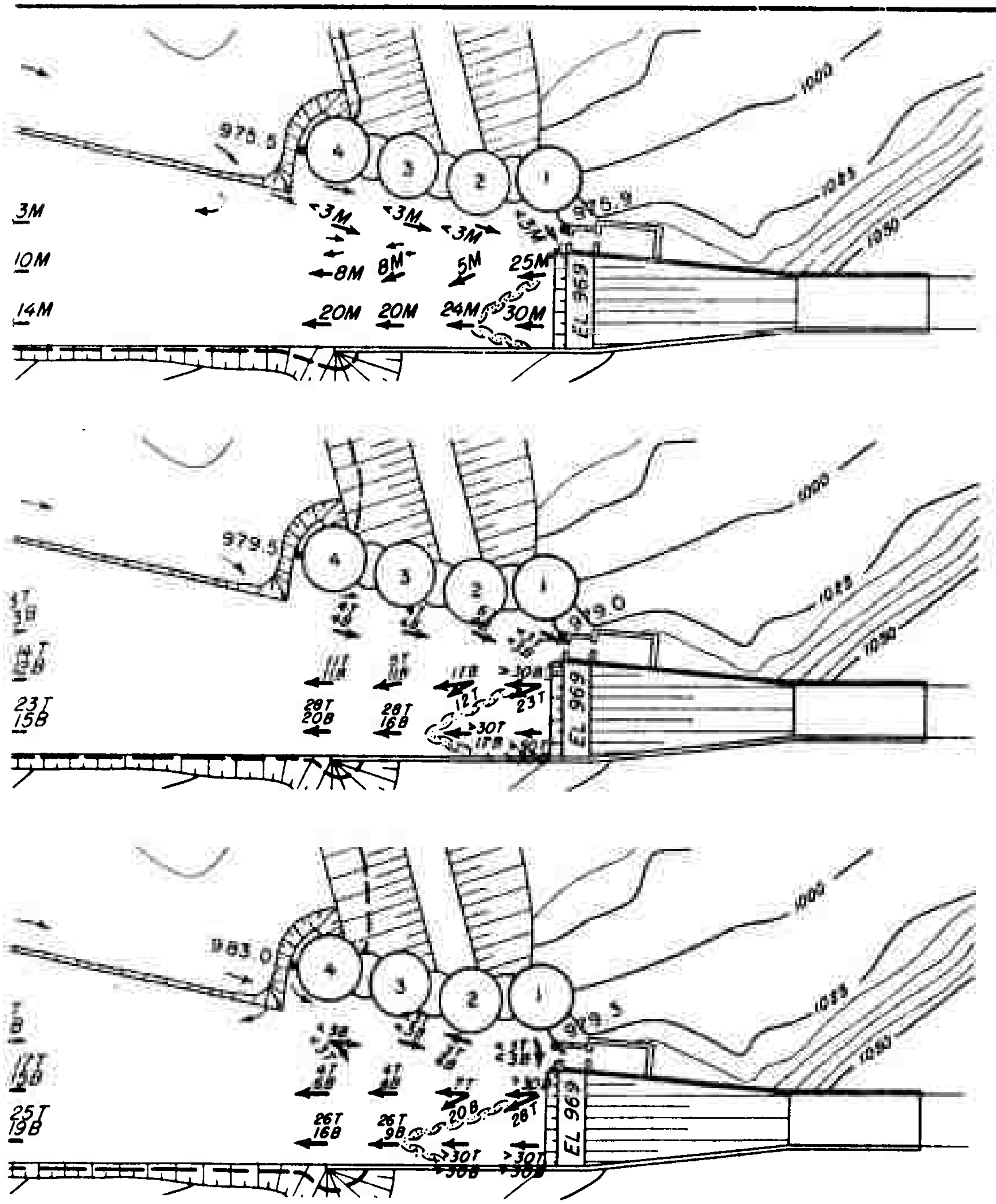
RIVER DISCHARGE 20,000 CFS



RIVER DISCHARGE 30,000 CFS

NOTES

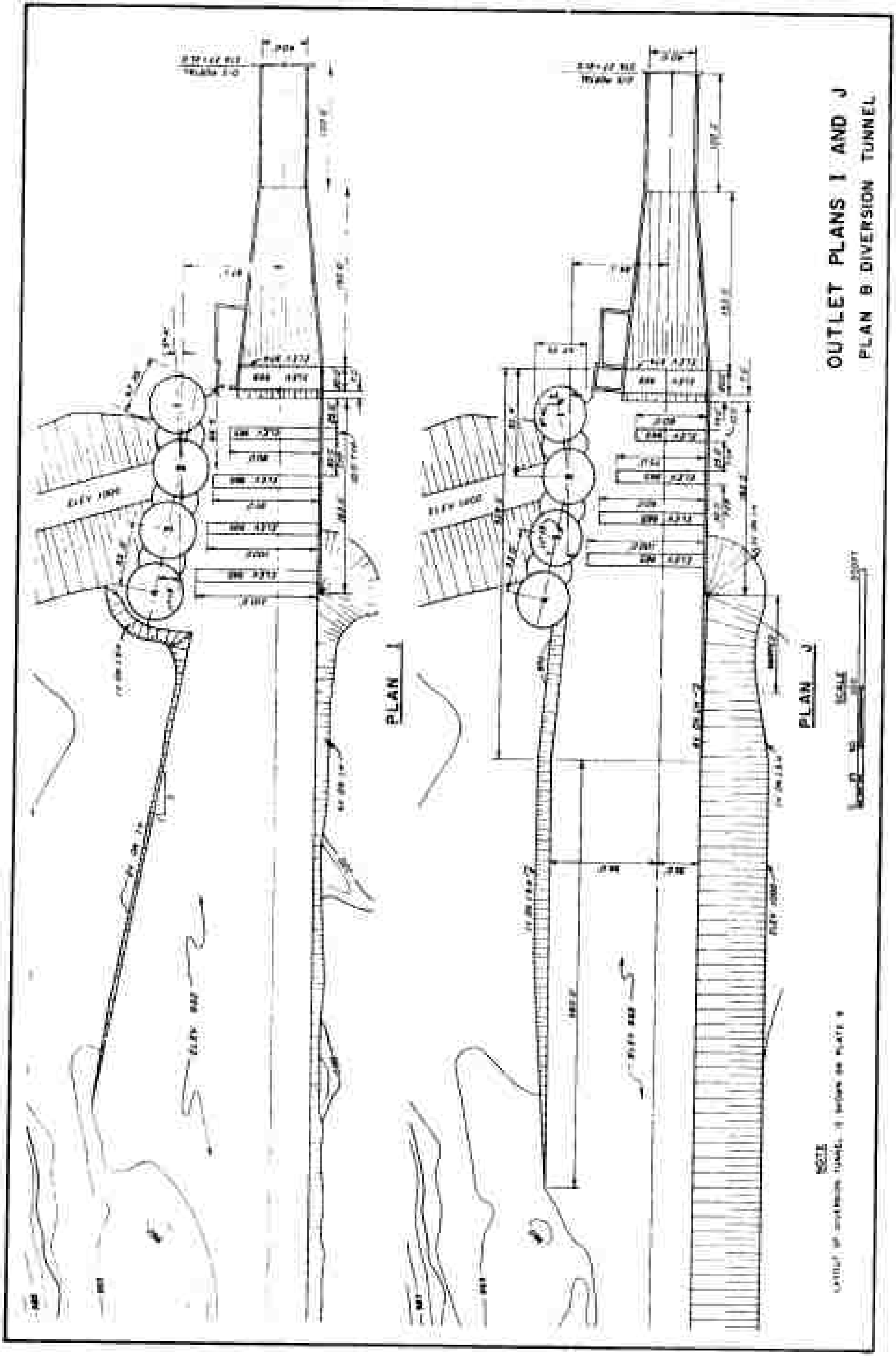
1. OUTLET DETAILS SHOWN ON PLATE 17.
2. SILLS ARE OMITTED FOR CLARITY.

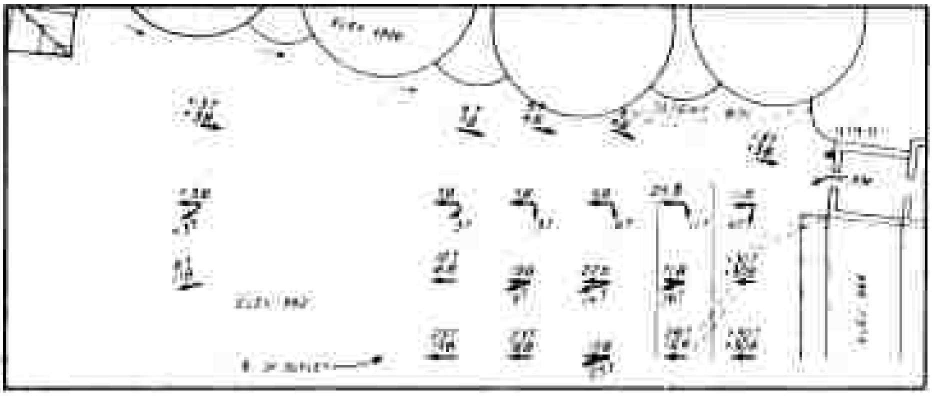


FLOW CONDITIONS

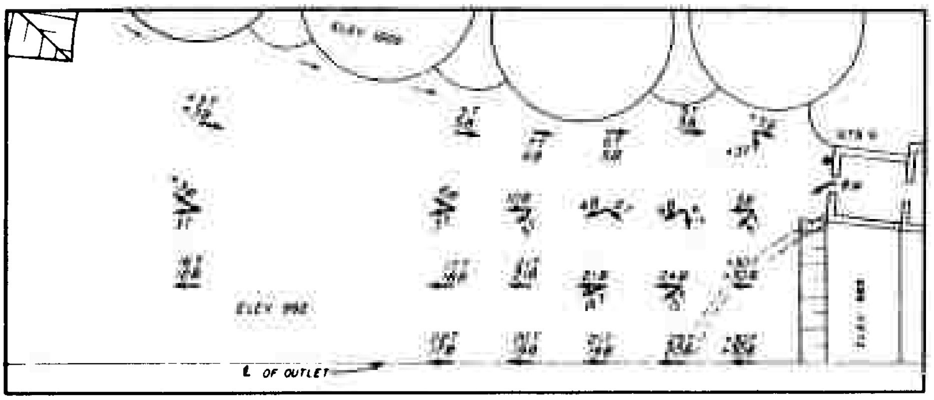
PLAN G OUTLET
PLAN B DIVERSION CHANNEL

3 of 3

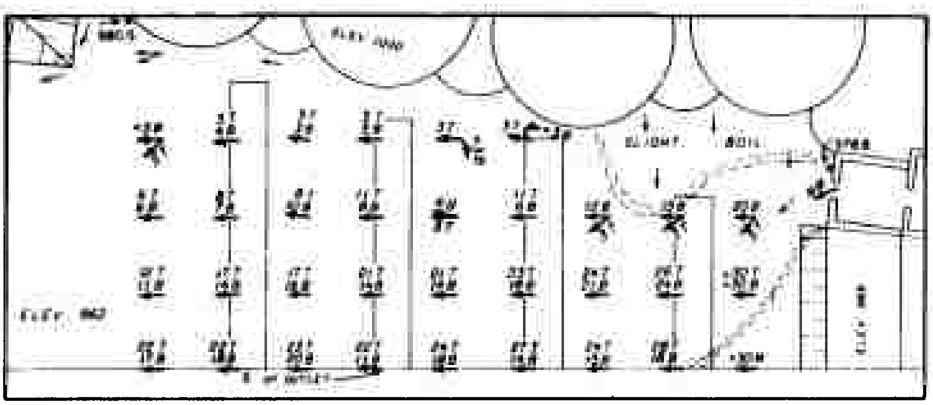

OUTLET PLANS I AND J
PLAN B DIVERSION TUNNEL
PLAN I
PLAN J
SCALE
NOTE



PLAN G



PLAN H



PLAN I

NOTE

OUTLET DETAILS ARE SHOWN ON PLATES 17 AND 20

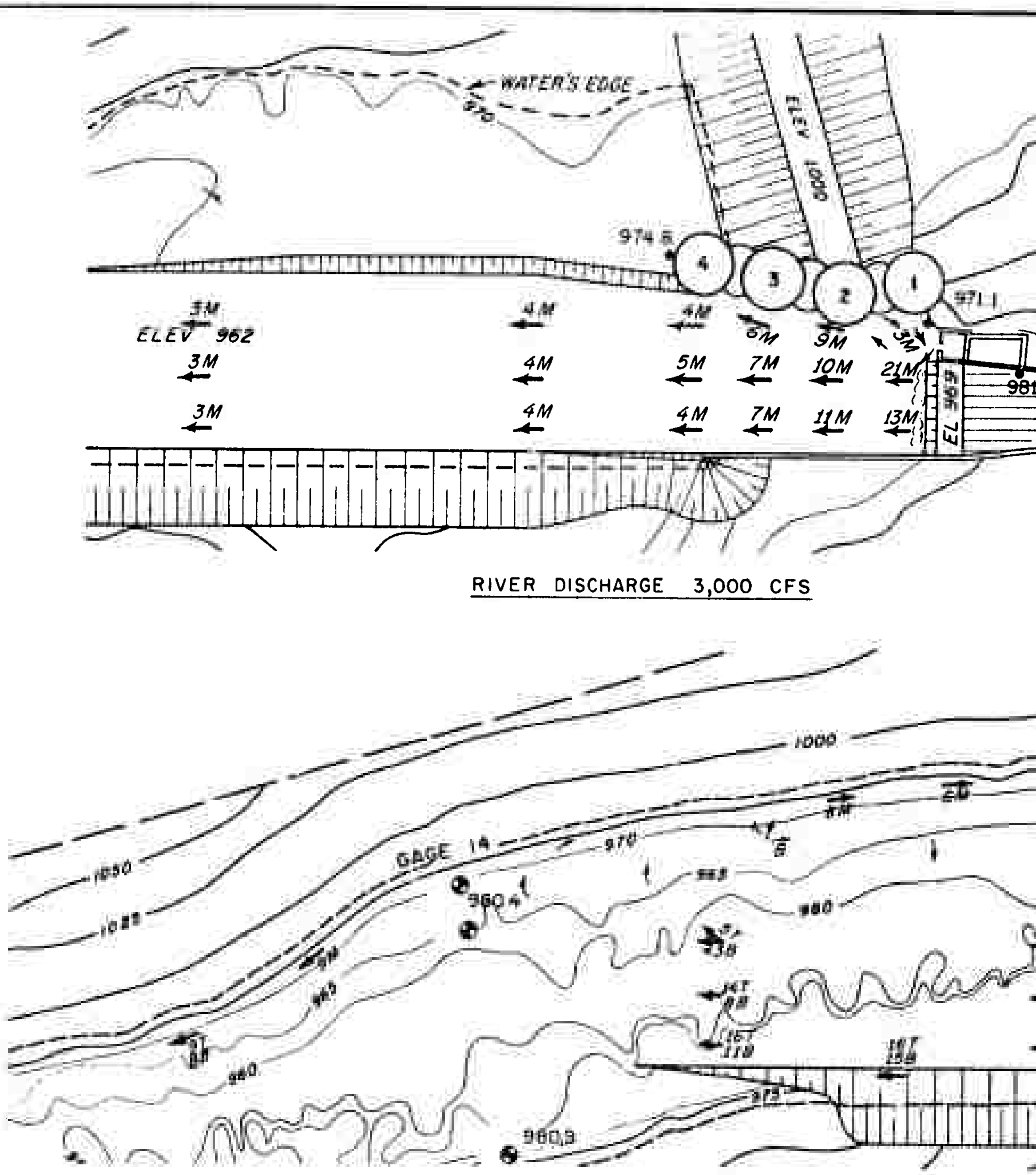
LEGEND

VELOCITY MEASUREMENTS IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
9805 ● WATER-SURFACE ELEVATIONS

VELOCITIES

OUTLET PLANS G TO I

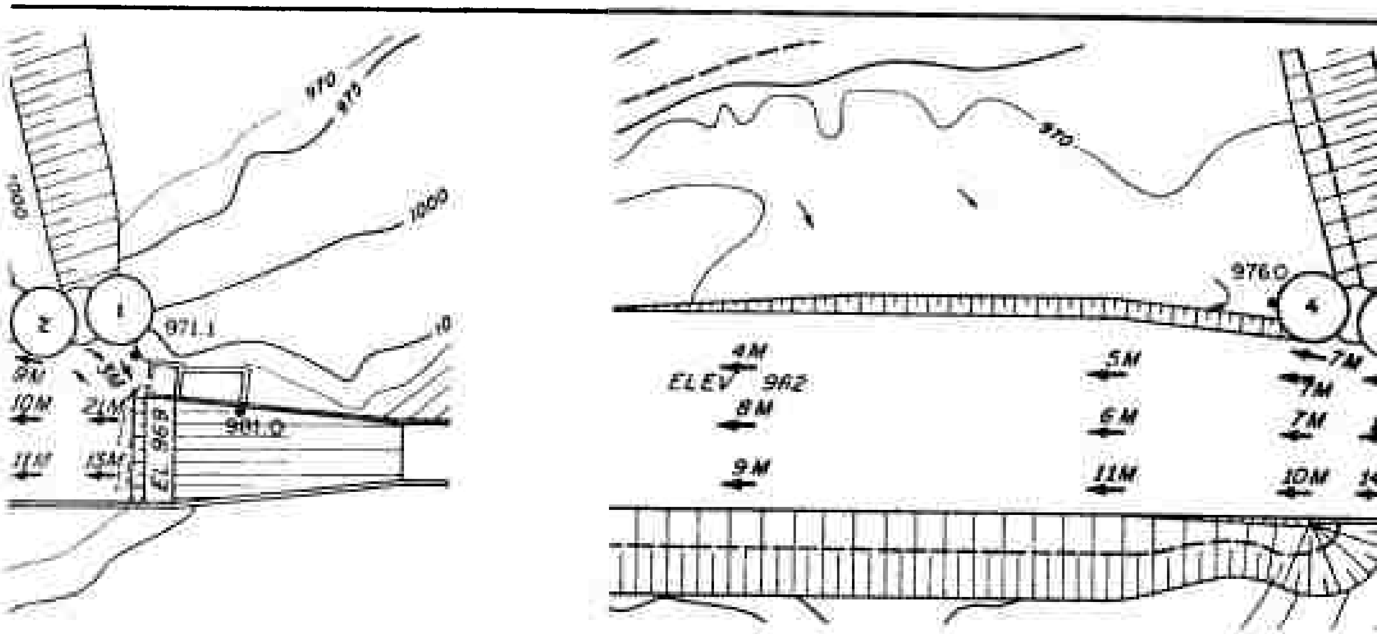
PLAN B DIVERSION TUNNEL
RIVER DISCHARGE 20000 CFS



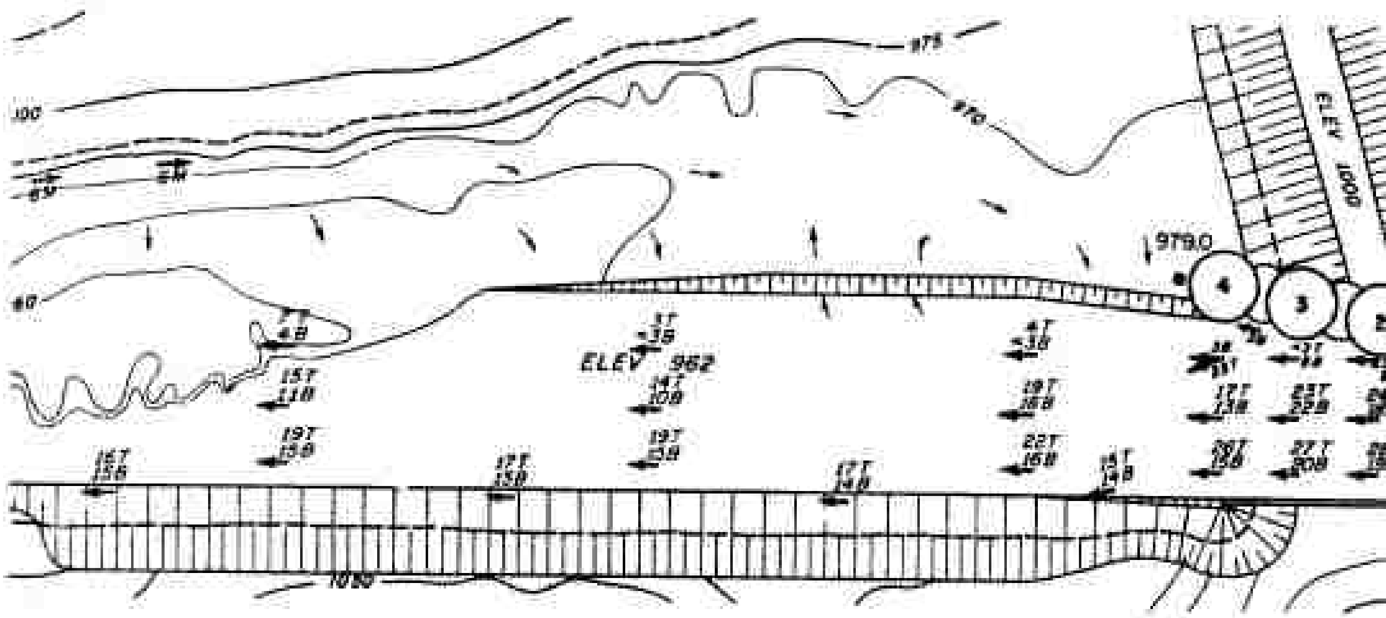
LEGEND

4 (arrow)	VELOCITY MEASUREMENTS IN FPS
T	3-FT DEPTH
M	MID-DEPTH
B	3 FT ABOVE BOTTOM
980.9 ●	WATER-SURFACE ELEVATIONS

Plate 23



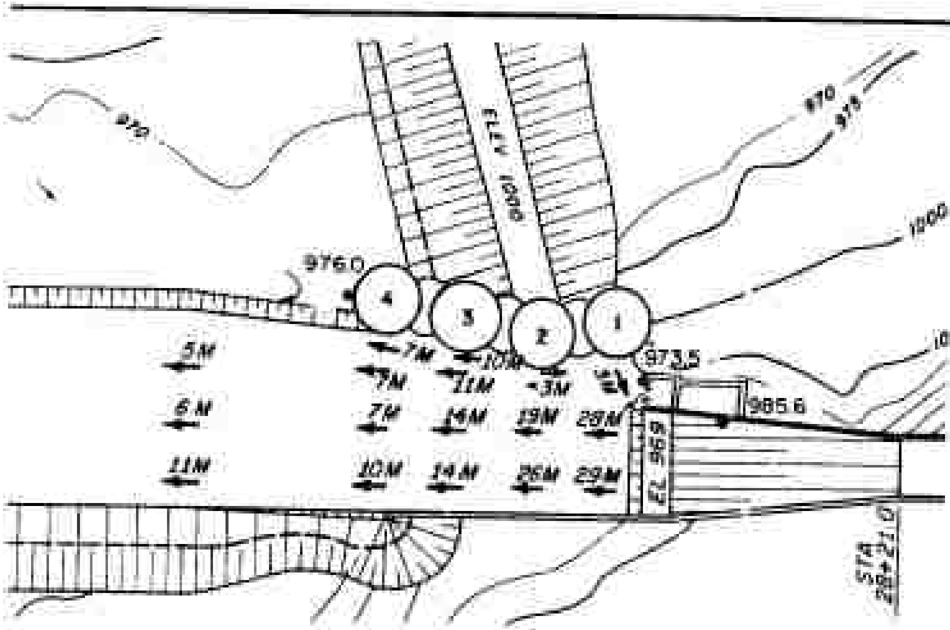
RIVER DISCHARGE 10,000



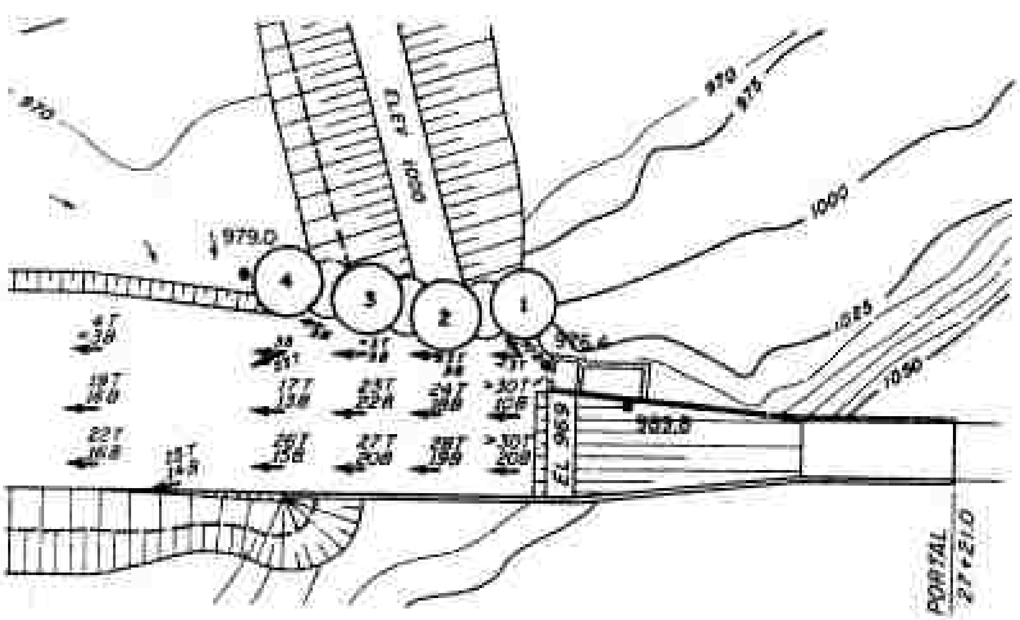
RIVER DISCHARGE 20,000 CFS

NOTES

1. OUTLET DETAILS ARE SHOWN ON PLATE 20.
2. SILLS ARE OMITTED FOR CLARITY.



RIVER DISCHARGE 10,000 CFS

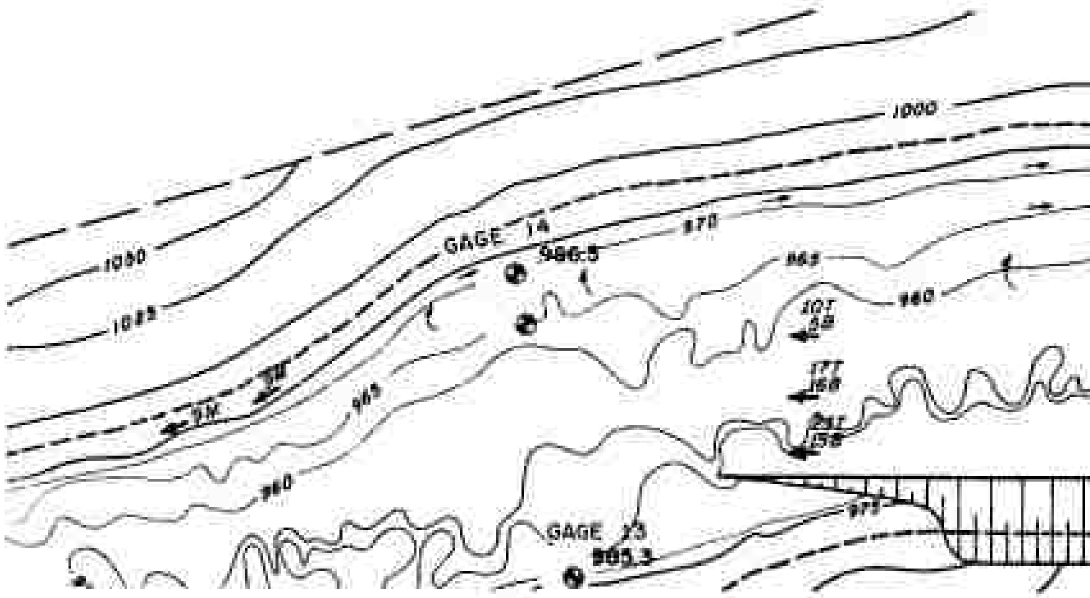


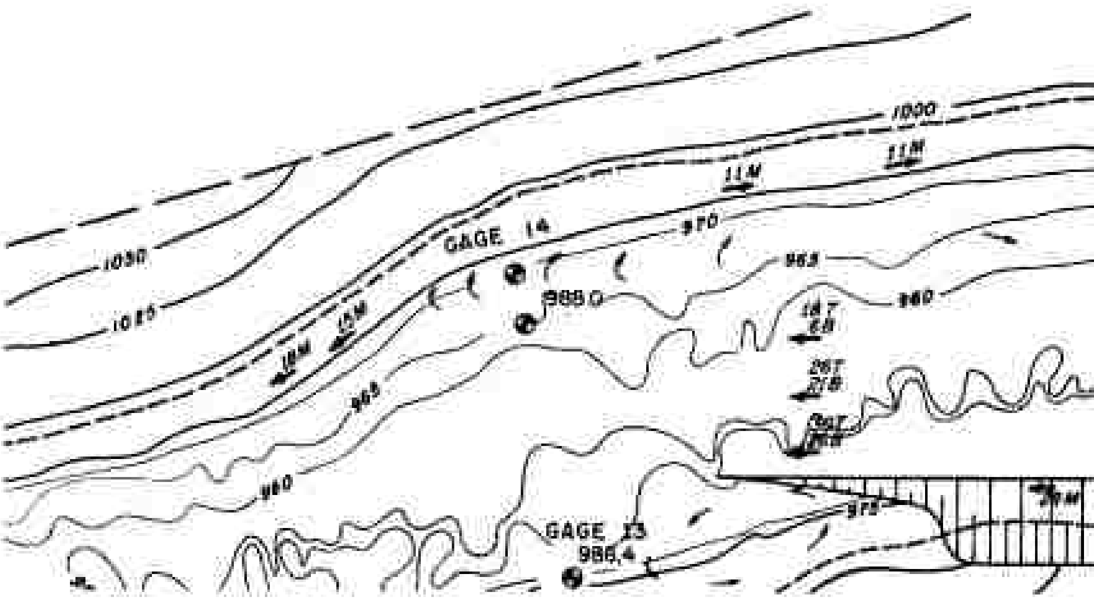
FLOW CONDITIONS

PLAN J OUTLET
PLAN B DIVERSION TUNNEL

RIVER DISCHARGE 3 000 TO 20 000 CFS

3 of 3



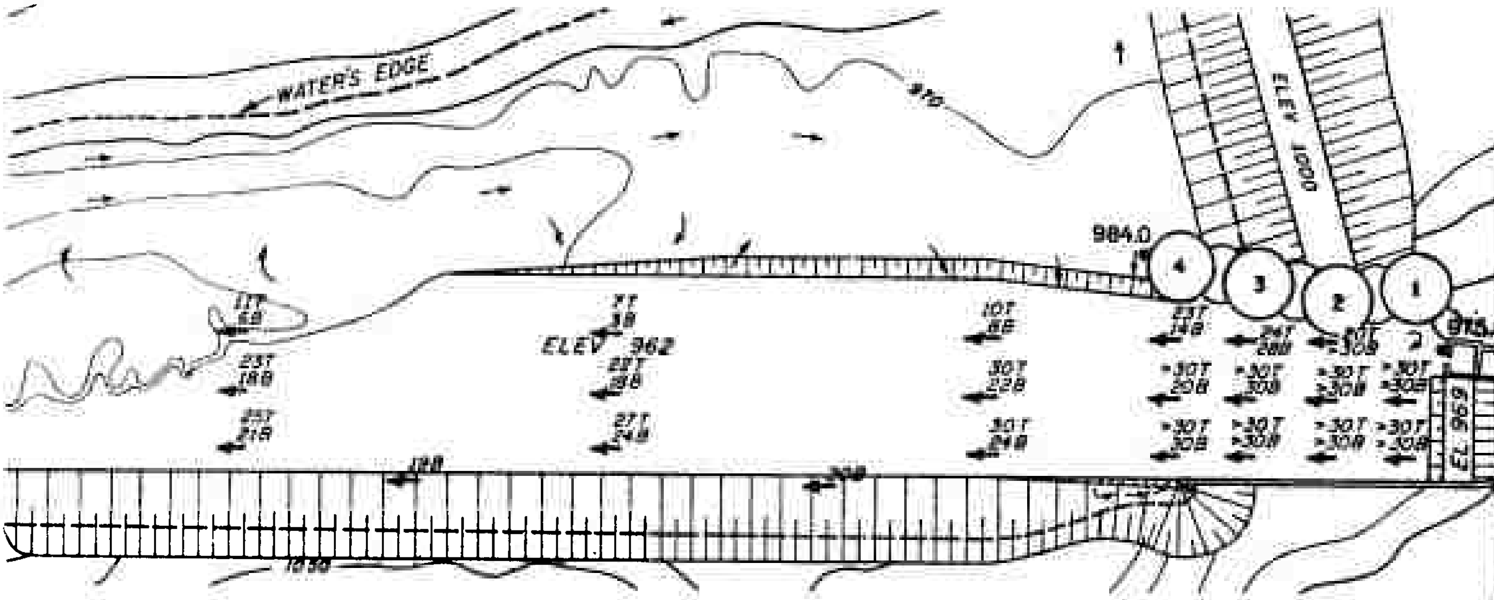


LEGEND

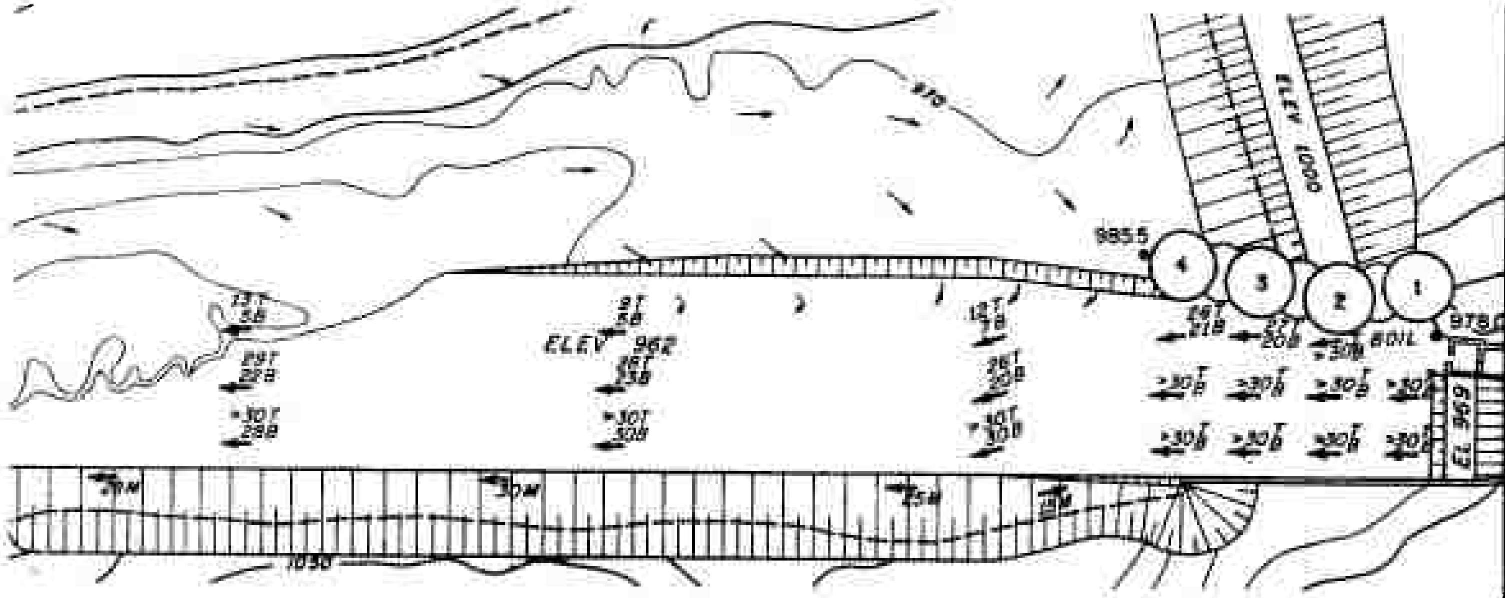
← 4	VELOCITY MEASUREMENTS IN FPS
T	3-FT DEPTH
M	MID-DEPTH
B	3 FT ABOVE BOTTOM
986.4 ●	WATER-SURFACE ELEVATIONS

Plate 23

1



RIVER DISCHARGE 44,000 CFS

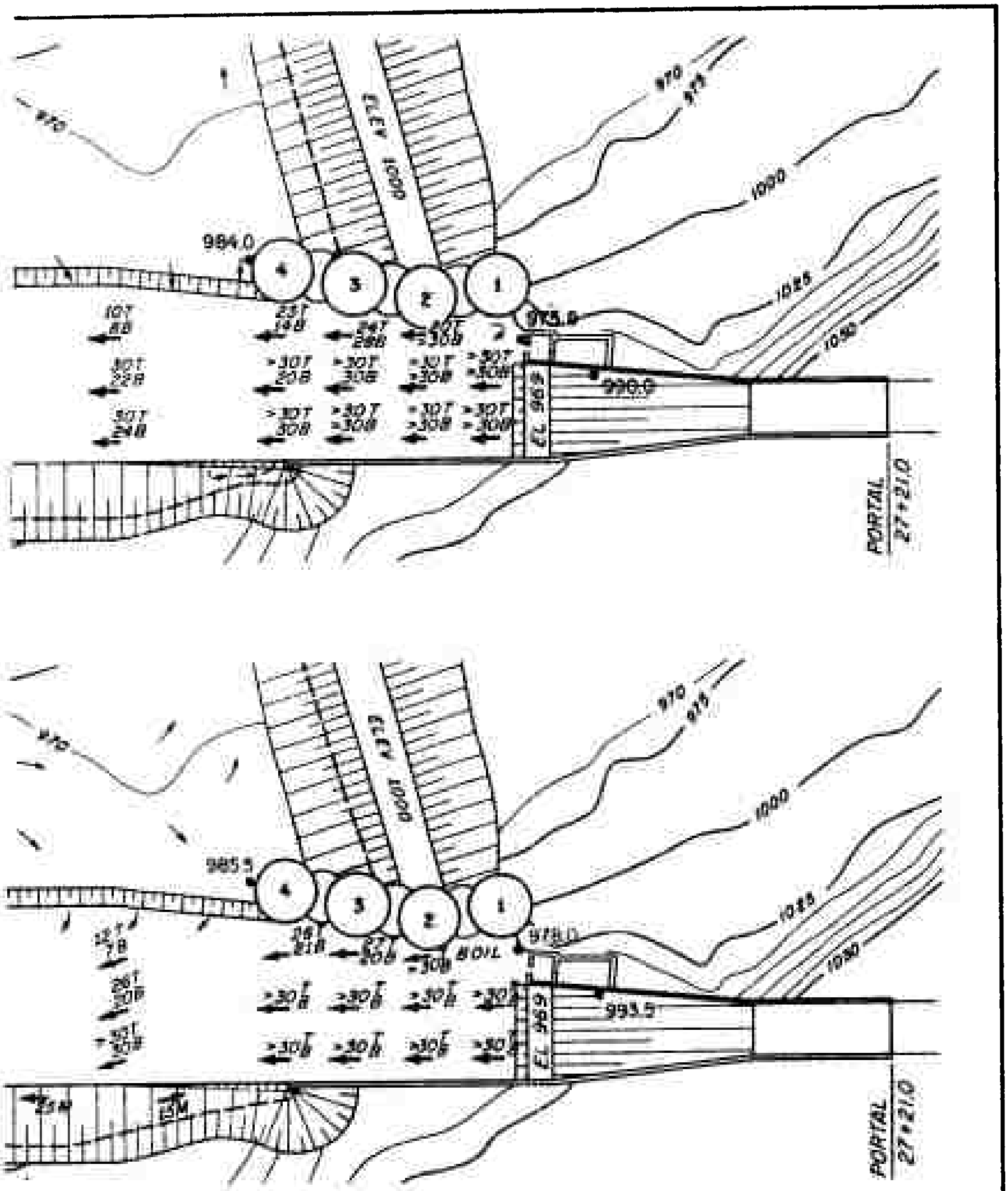


RIVER DISCHARGE 65,000 CFS

NOTES

1. OUTLET DETAILS ARE SHOWN ON PLATE 20.
2. SILLS ARE OMITTED FOR CLARITY.

RIVE



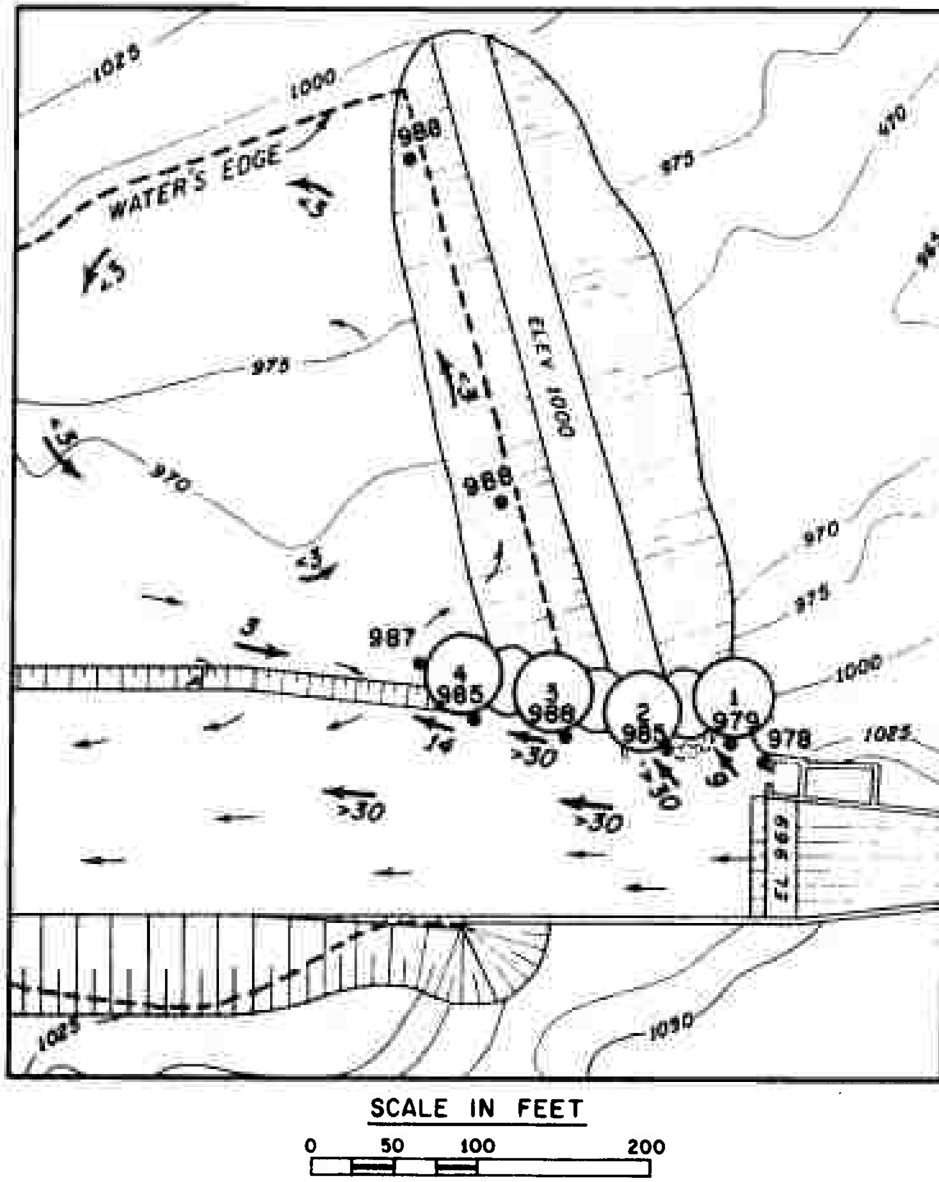
FLOW CONDITIONS

PLAN J OUTLET

PLAN B DIVERSION TUNNEL

RIVER DISCHARGE 44000 AND 65000 CFS

3 of 3



LEGEND

VELOCITY MEASUREMENTS IN FPS 3 FT ABOVE BOTTOM

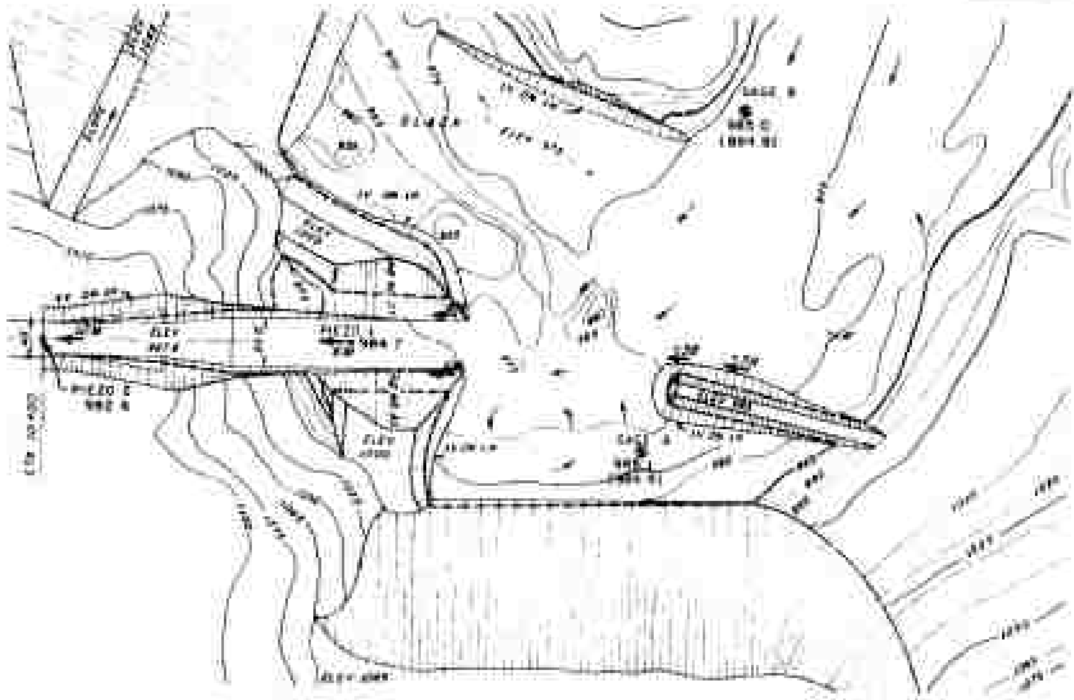
987● WATER-SURFACE ELEVATIONS

NOTES

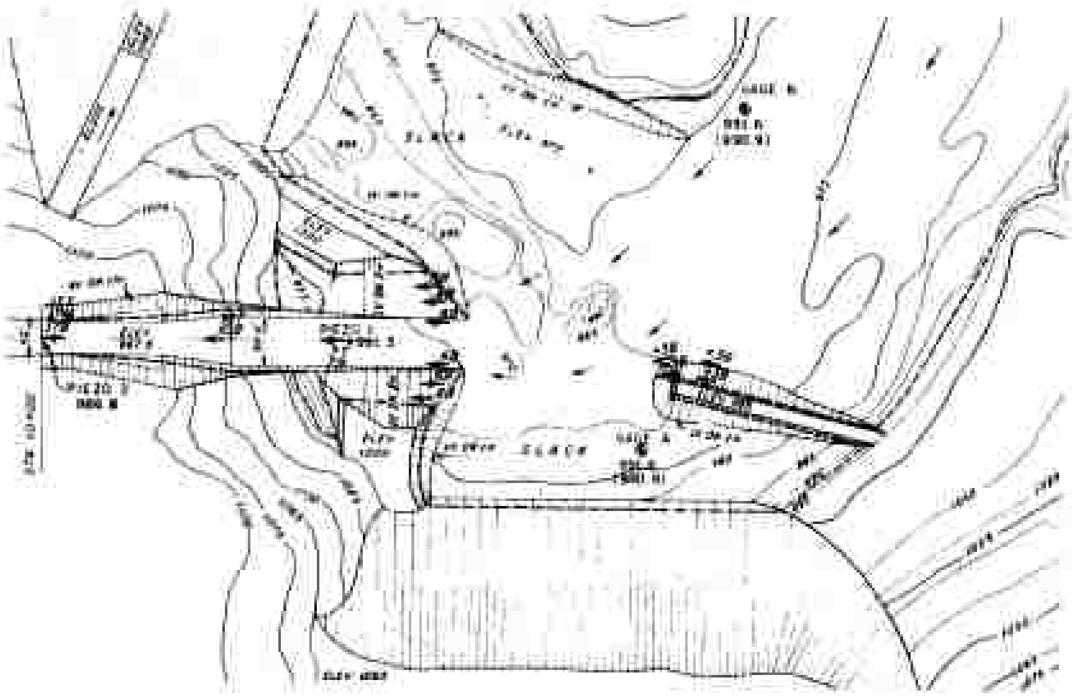
1. OUTLET DETAILS ARE SHOWN ON PLATE 20.
2. TAILWATER ELEV 992.2 (MAXIMUM BACKWATER EFFECT FROM CLEARWATER RIVER).
3. SILLS ARE OMITTED FOR CLARITY.

FLOW CONDITIONS

PLAN J OUTLET
PLAN B DIVERSION TUNNEL
RIVER DISCHARGE 68 000 CFS



RIVER DISCHARGE 5000 CFS



RIVER DISCHARGE 10000 CFS

SCALE IN FEET

0 50 100 200

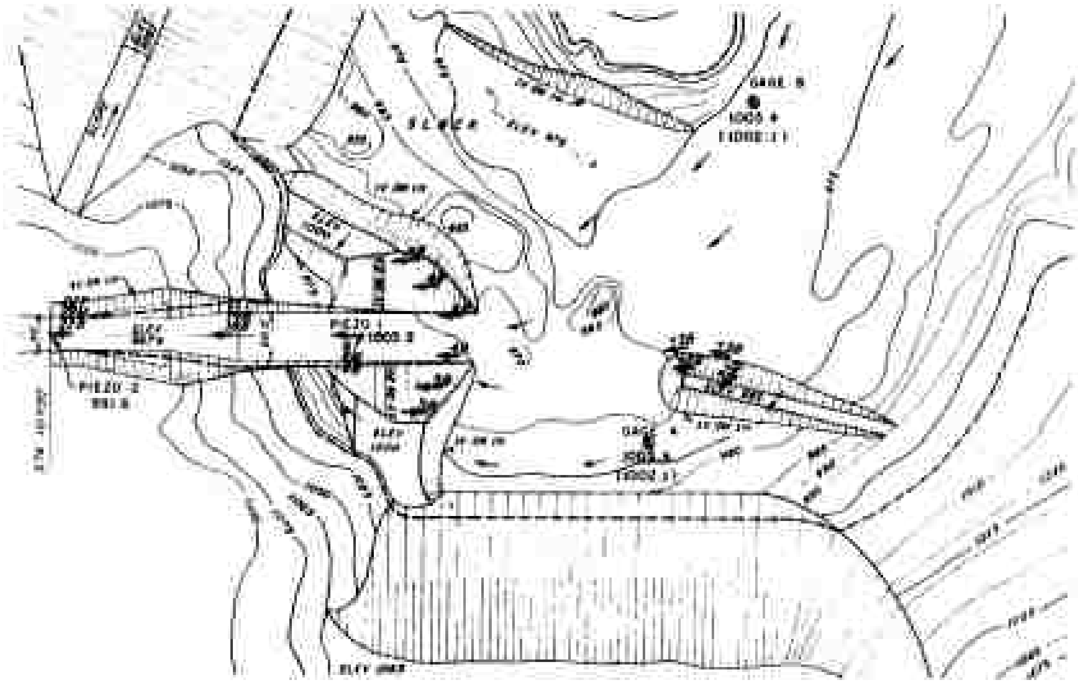
LEGEND

- VELOCITY MEASUREMENTS IN FPS
- T 3-FT DEPTH
- M MID-DEPTH
- B 3 FT ABOVE BOTTOM
- ● WATER-SURFACE ELEVATIONS
- ( ) CORRECTED FOR TUNNEL ROUGHNESS VARIATION, MODEL TO PROTOTYPE

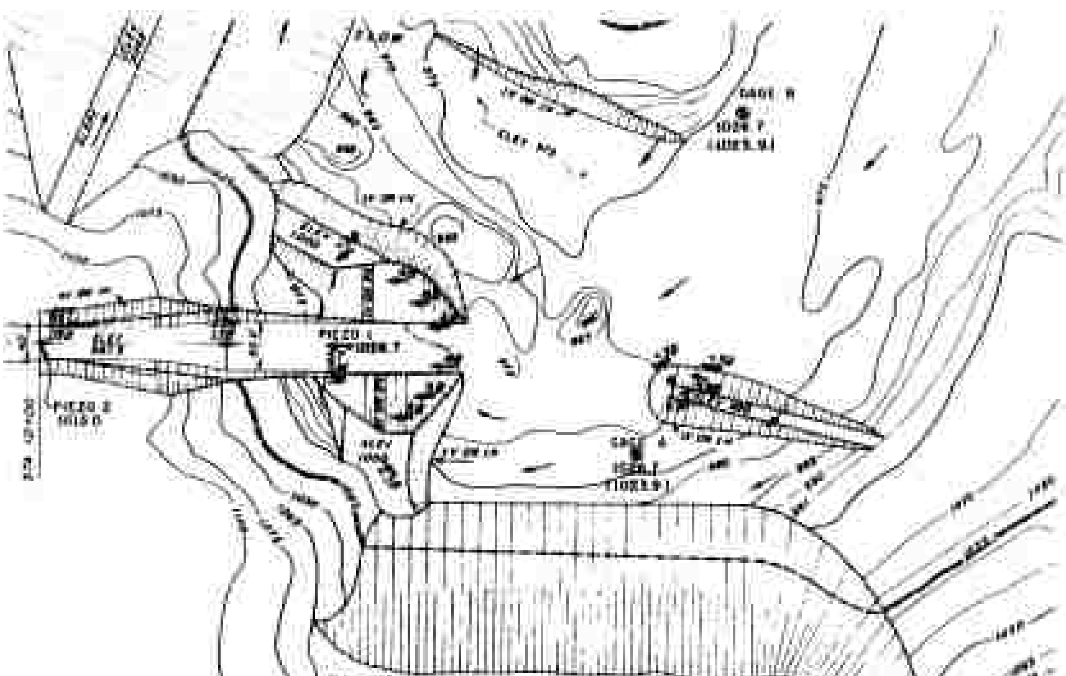
FLOW CONDITIONS

PARTIAL REMOVAL OF DIKE AT TUNNEL INTAKE

RIVER DISCHARGES 5000 AND 10000 CFS



RIVER DISCHARGE 20000 CFS



RIVER DISCHARGE 44000 CFS

SCALE IN FEET

0 50 100 200

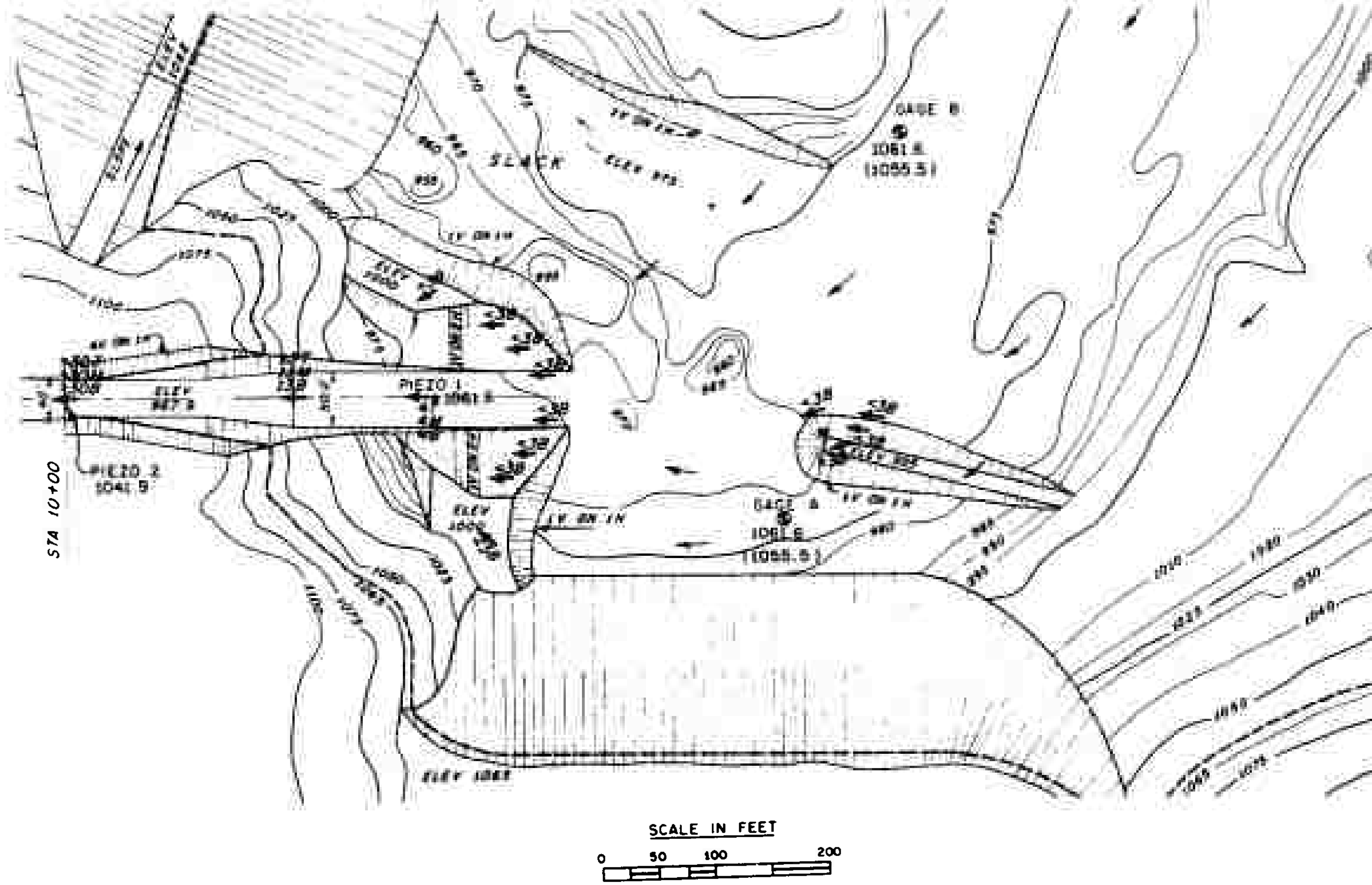
LEGEND

- VELOCITY MEASUREMENTS IN FPS
- T 3-FT DEPTH
- M MID-DEPTH
- B 3 FT ABOVE BOTTOM
- ● WATER-SURFACE ELEVATIONS
- ( ) CORRECTED FOR TUNNEL ROUGHNESS VARIATION, MODEL TO PROTOTYPE

FLOW CONDITIONS

PARTIAL REMOVAL OF DIKE AT TUNNEL INTAKE

RIVER DISCHARGES 20000 AND 44000 CFS



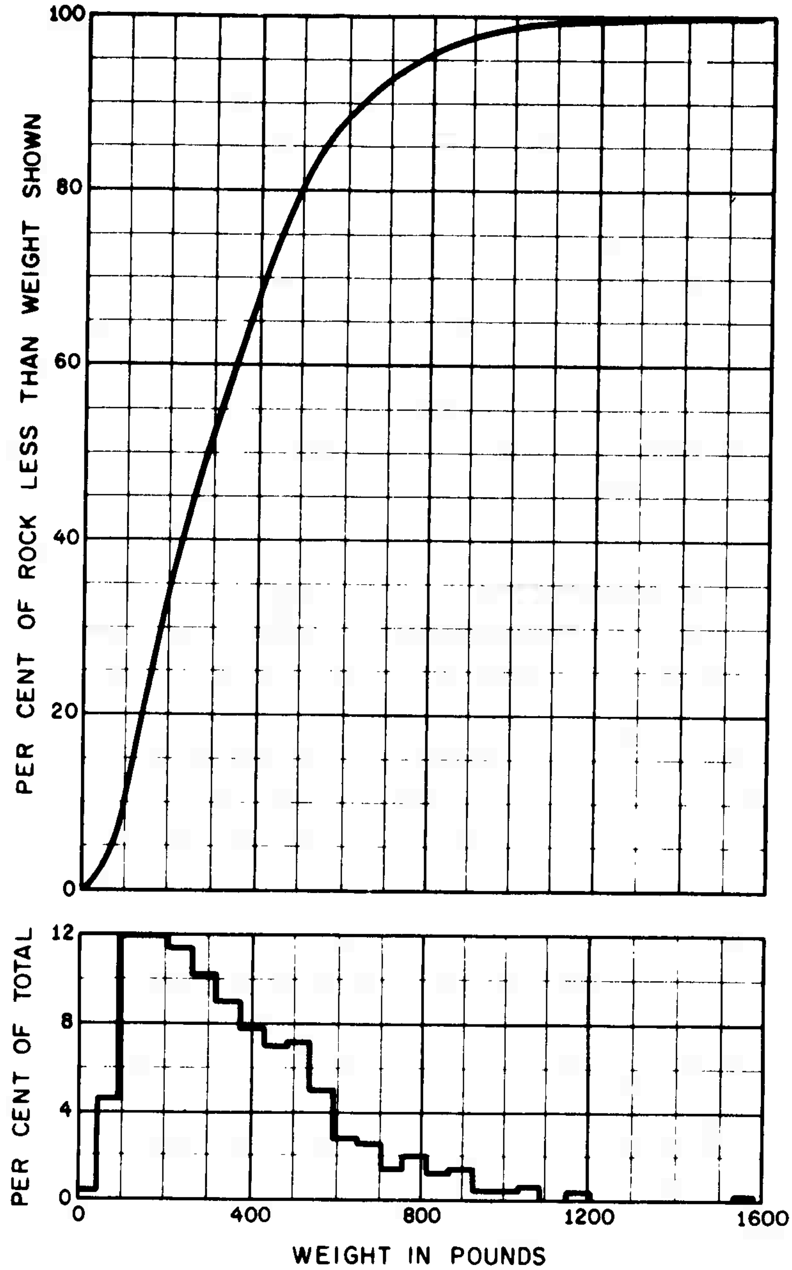
LEGEND

- 4 VELOCITY MEASUREMENTS IN FPS
- T 3-FT DEPTH
- M MID-DEPTH
- B 3 FT ABOVE BOTTOM
- ● WATER-SURFACE ELEVATIONS
- ( ) CORRECTED FOR TUNNEL ROUGHNESS VARIATION, MODEL TO PROTOTYPE.

FLOW CONDITIONS

PARTIAL REMOVAL OF DIKE AT TUNNEL ENTRANCE

RIVER DISCHARGE 65 000 CFS

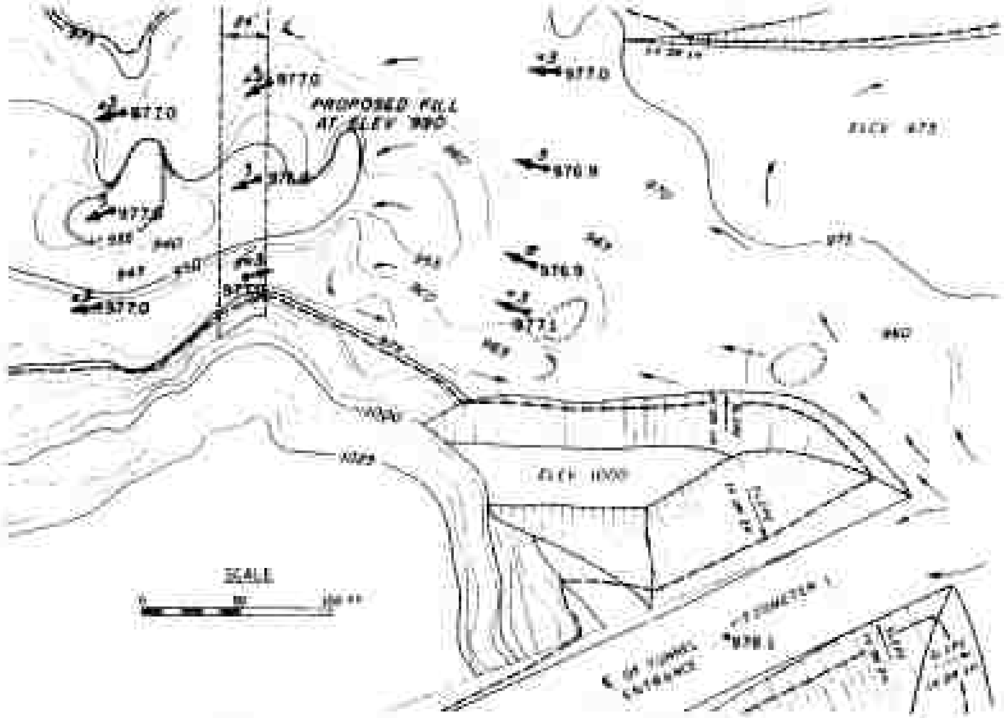


NOTES

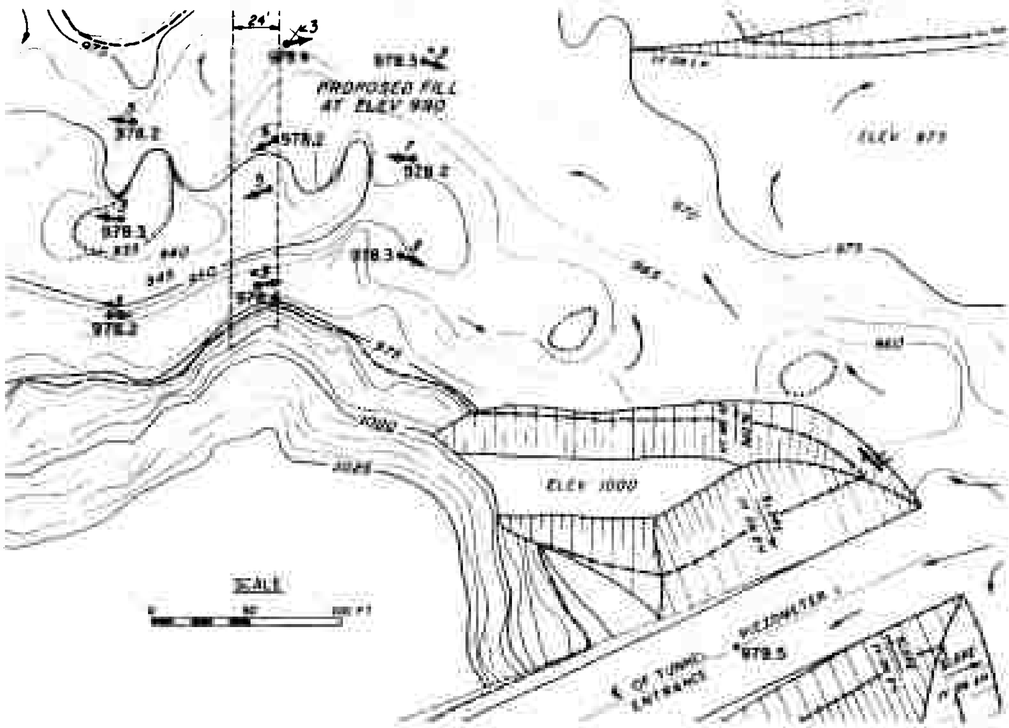
1. ROCK WAS CRUSHED GRANITE-GNEISS FROM DWORSHAK DAMSITE.
2. GRADATION BASED ON 500 PIECE SAMPLE.

QUARRY-RUN ROCK GRADATION

MODEL COFFERDAM CLOSURE



RIVER DISCHARGE 7000 CFS, TUNNEL DISCHARGE 1000 CFS



RIVER DISCHARGE 10 000 CFS, TUNNEL DISCHARGE 3000 CFS

LEGEND

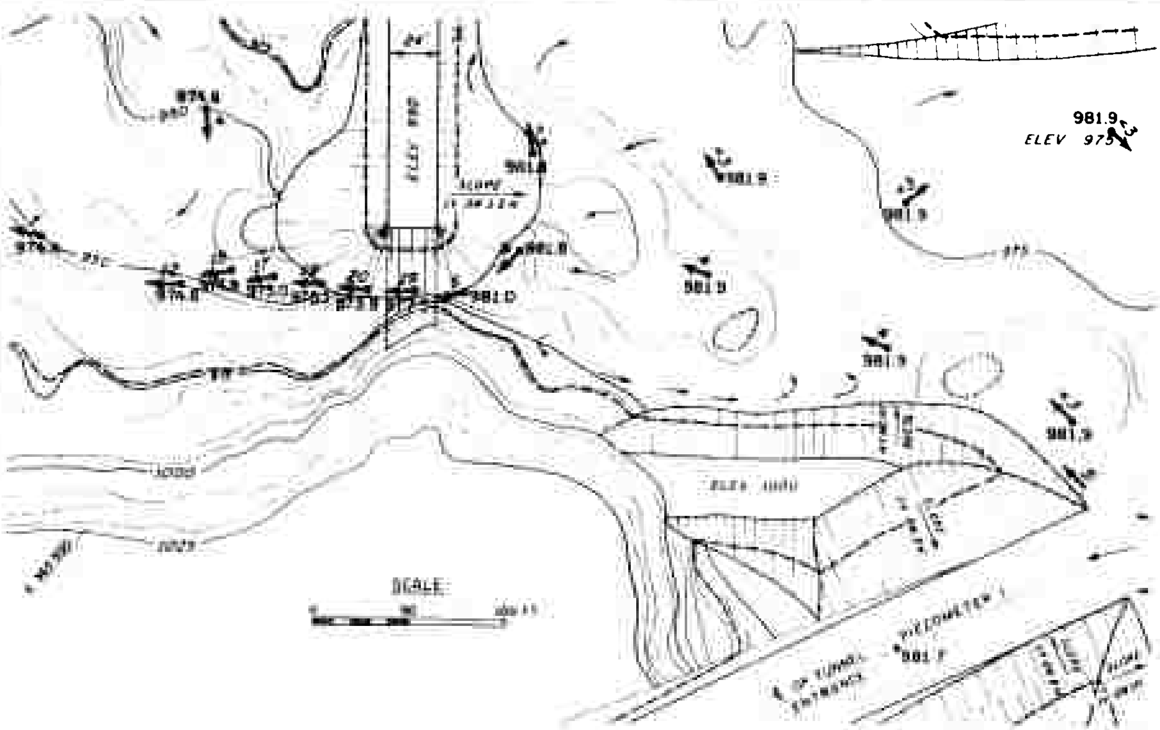
3 VELOCITIES (FPS) AT MID-DEPTH

978.2 WATER - SURFACE ELEVATIONS

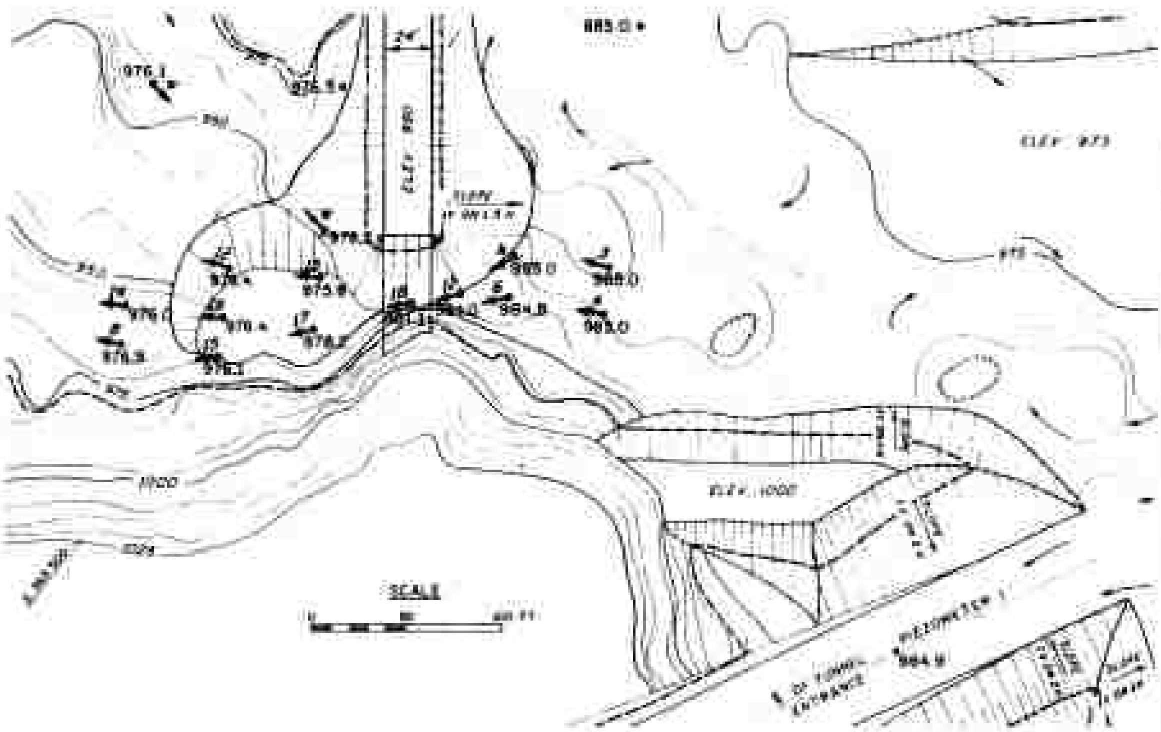
FLOW CONDITIONS BEFORE CLOSURE

PLAN A UPSTREAM COFFERDAM

PLATE 29



RIVER DISCHARGE 7000 CFS, TUNNEL DISCHARGE 4400 CFS



RIVER DISCHARGE 10 000 CFS, TUNNEL DISCHARGE 6600 CFS

LEGEND

3 VELOCITIES (FPS) AT MID-DEPTH

985 1 • WATER-SURFACE ELEVATIONS

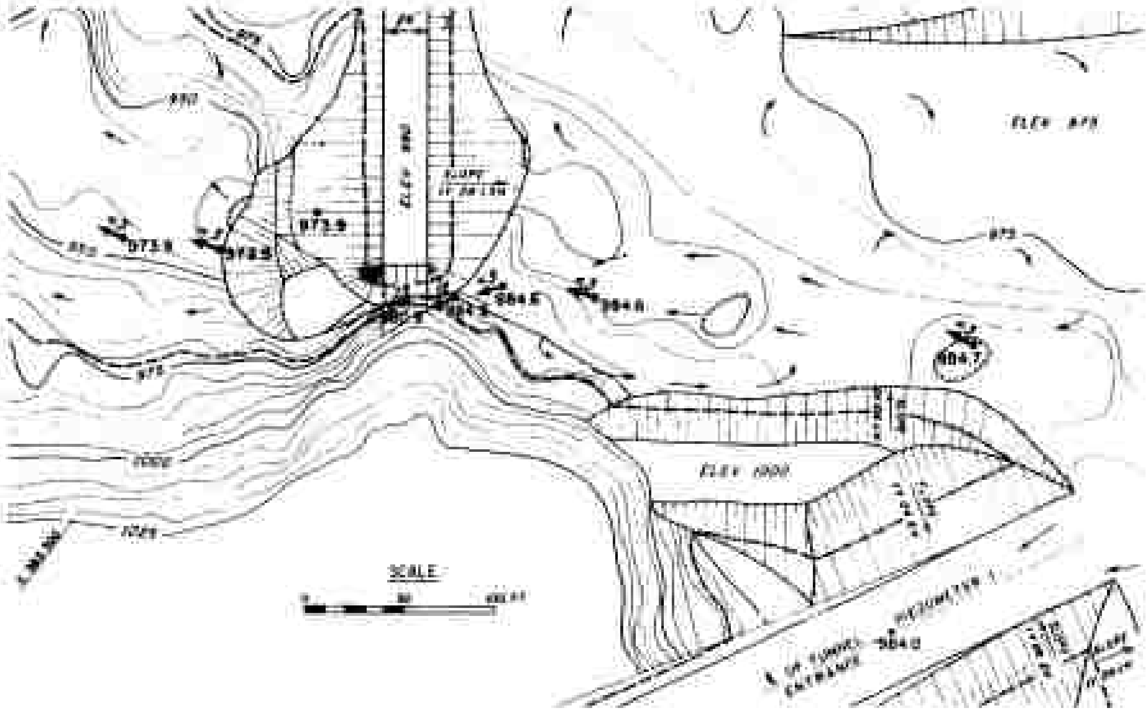
NOTE

CLOSURE GAP MEASURED ON UPSTREAM FACE OF FILL AT ELEV 990

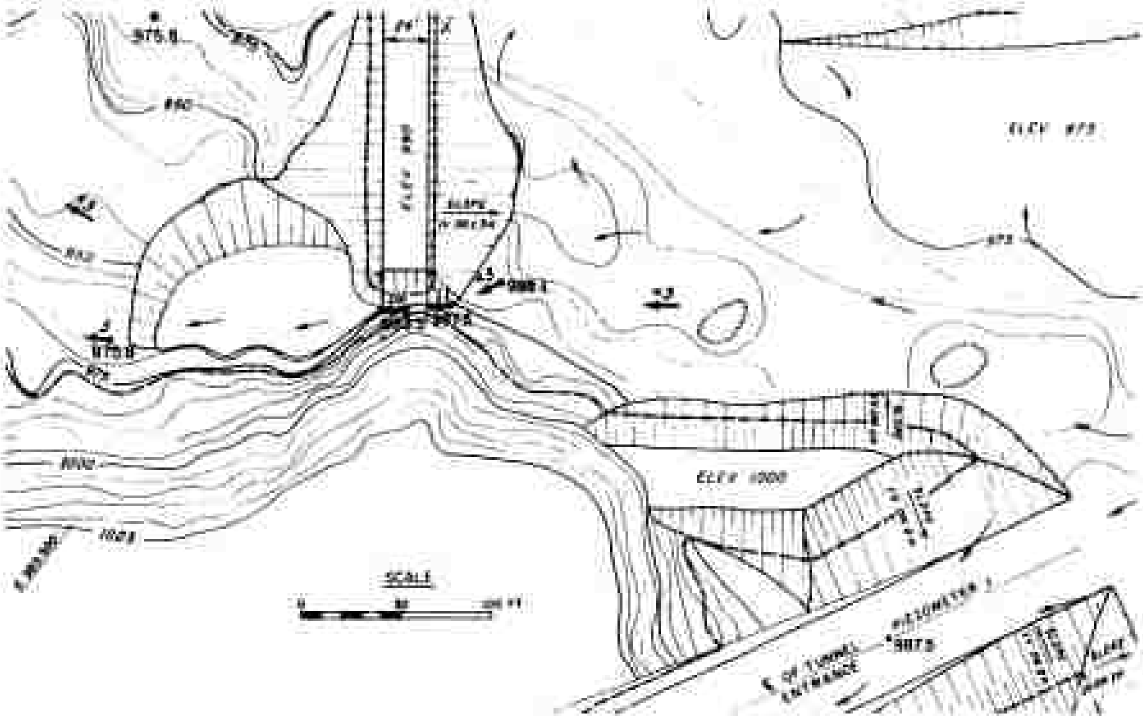
FLOW CONDITIONS DURING CLOSURE

PLAN A UPSTREAM COFFERDAM

50-FT GAP, FILL VOLUME 12 000 CU YD



RIVER DISCHARGE 7000 CFS, TUNNEL DISCHARGE 6000 CFS



RIVER DISCHARGE 10000 CFS, TUNNEL DISCHARGE 8800 CFS

LEGEND

3 VELOCITIES (FPS) AT MID-DEPTH

988.2• WATER-SURFACE ELEVATIONS

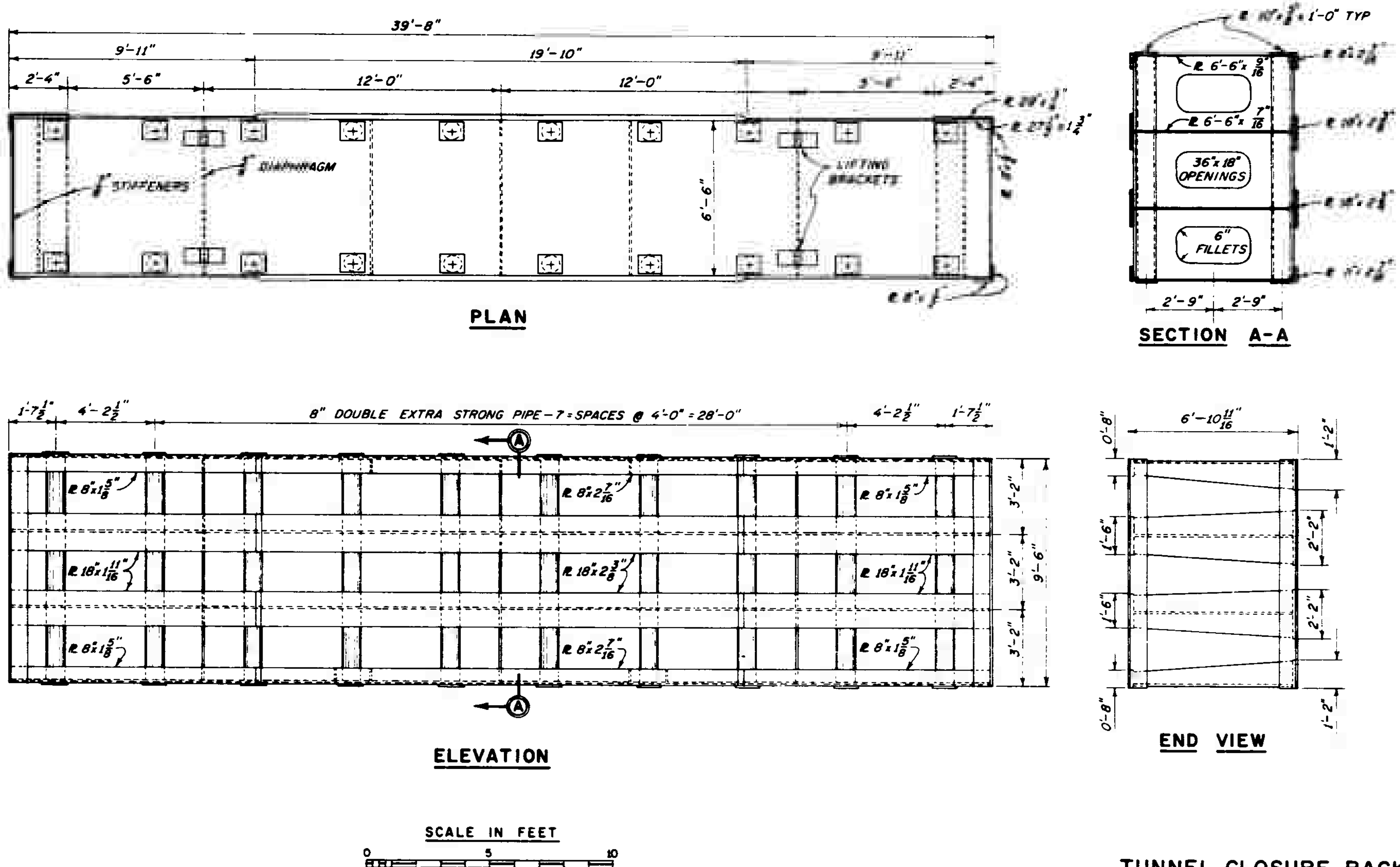
NOTE

CLOSURE GAP MEASURED ON UPSTREAM FACE OF FILL AT ELEV 990

FLOW CONDITIONS DURING CLOSURE

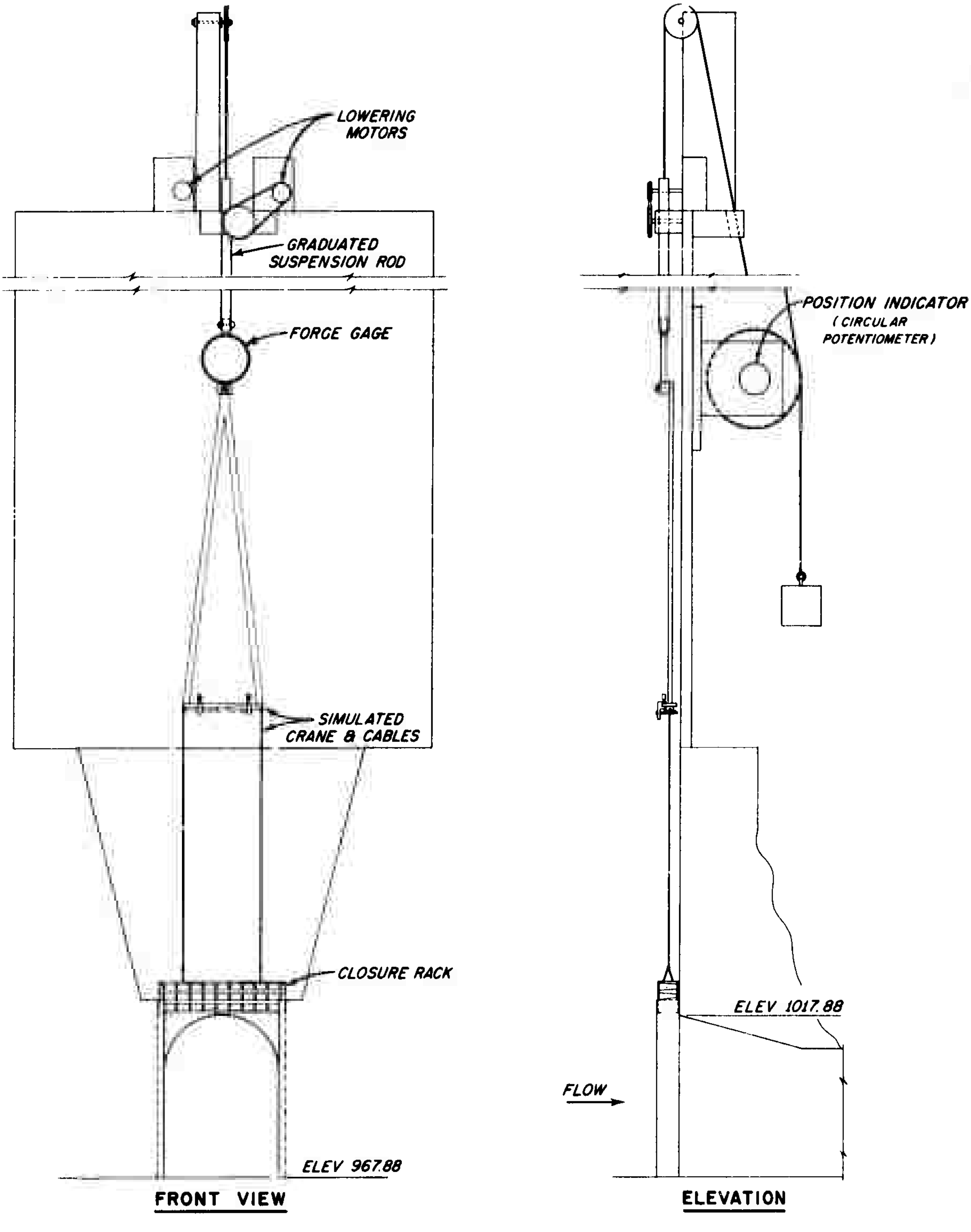
PLAN A UPSTREAM COFFERDAM

25-FT GAP, FILL VOLUME 17 000 CU YD



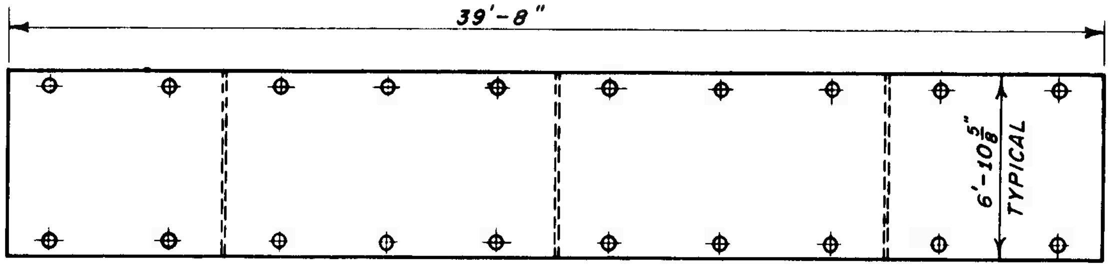
TUNNEL CLOSURE RACK

ORIGINAL DESIGN

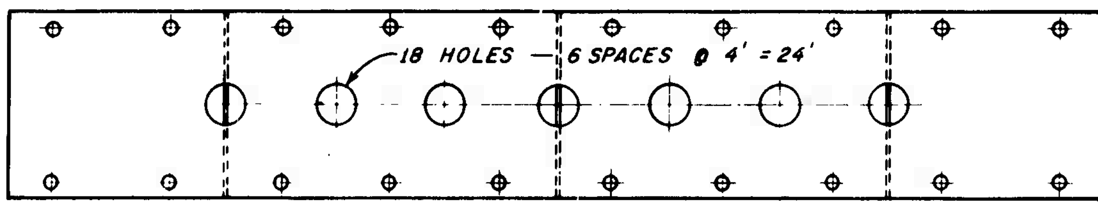


FORCE MEASURING APPARATUS

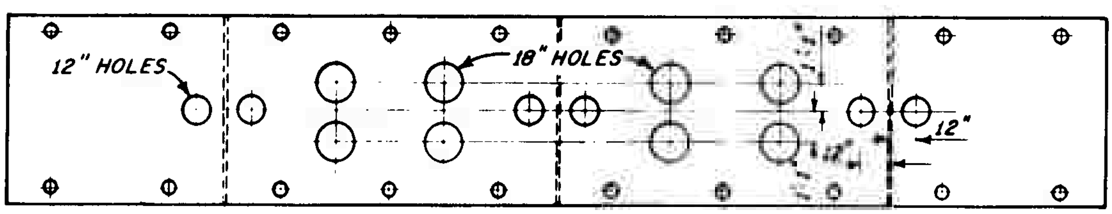
TUNNEL CLOSURE RACK



ORIGINAL



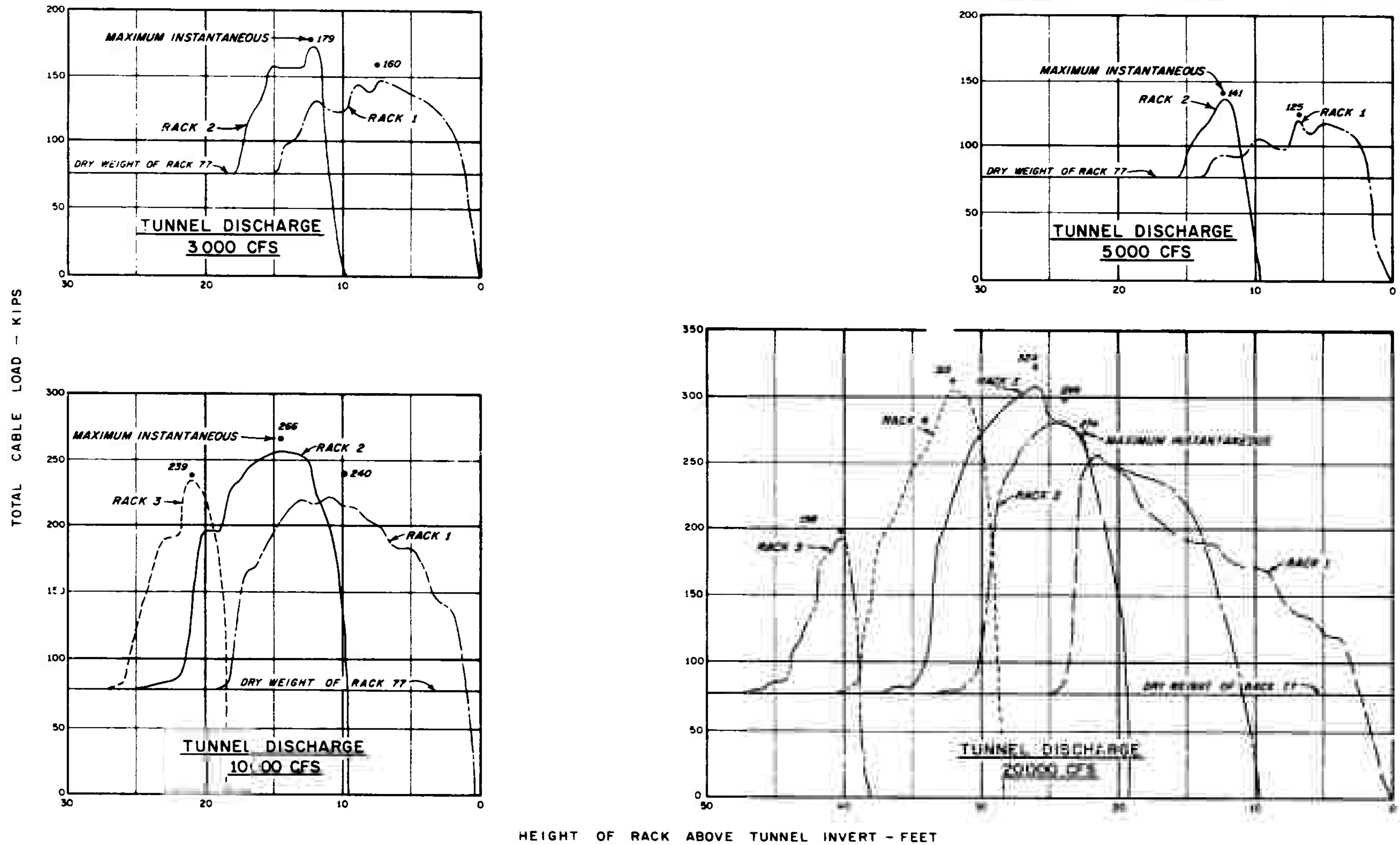
HOLE PATTERN 1



HOLE PATTERN 2

HORIZONTAL PLATE LAYOUT

TUNNEL CLOSURE RACK

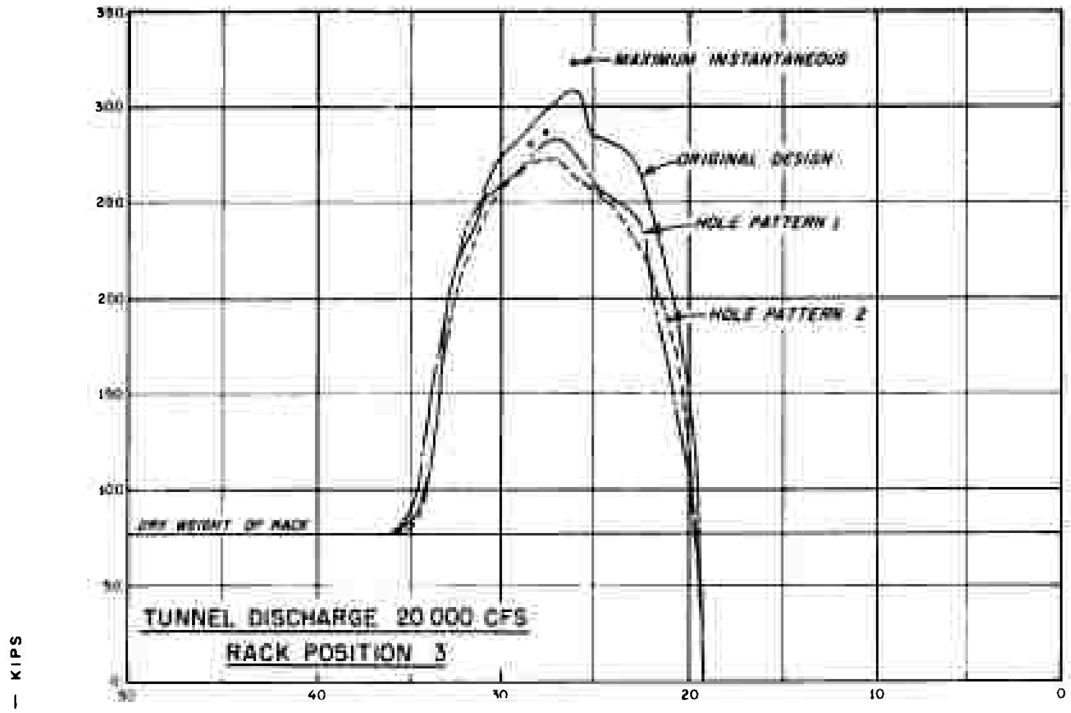


NOTES

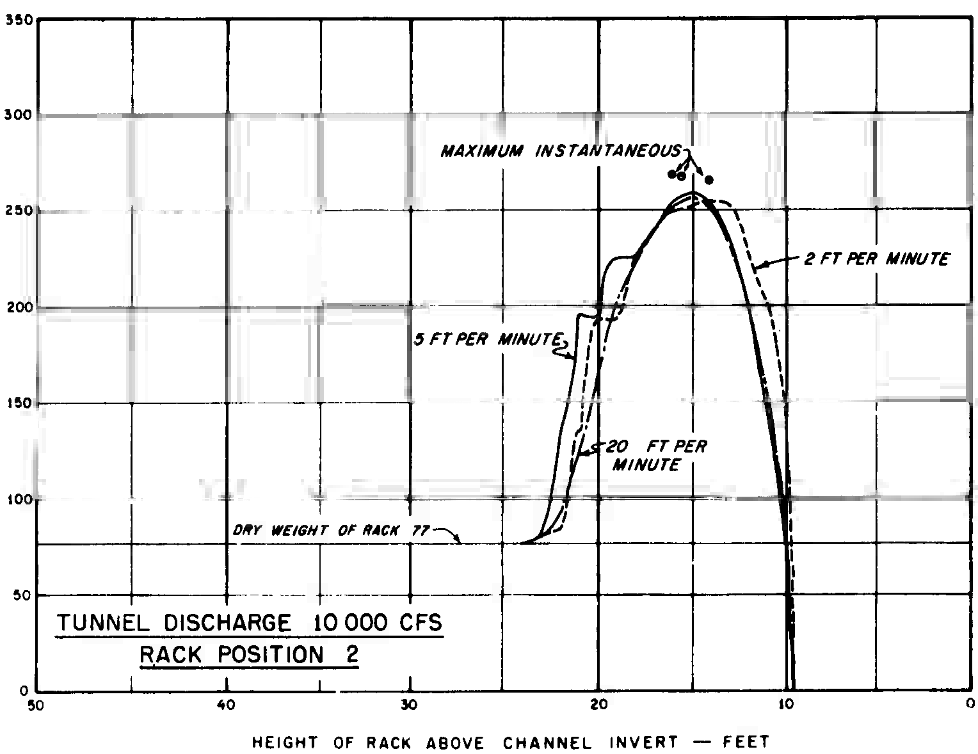
1 DETAILS OF CLOSURE RACKS ARE SHOWN ON PLATE 32
2 CURVES ARE PLOTS OF AVERAGE LOADING

CABLE LOADS ON TUNNEL CLOSURE RACKS

ORIGINAL DESIGN; LOWERING SPEED 2 FPM



EFFECTS OF HOLE PATTERN



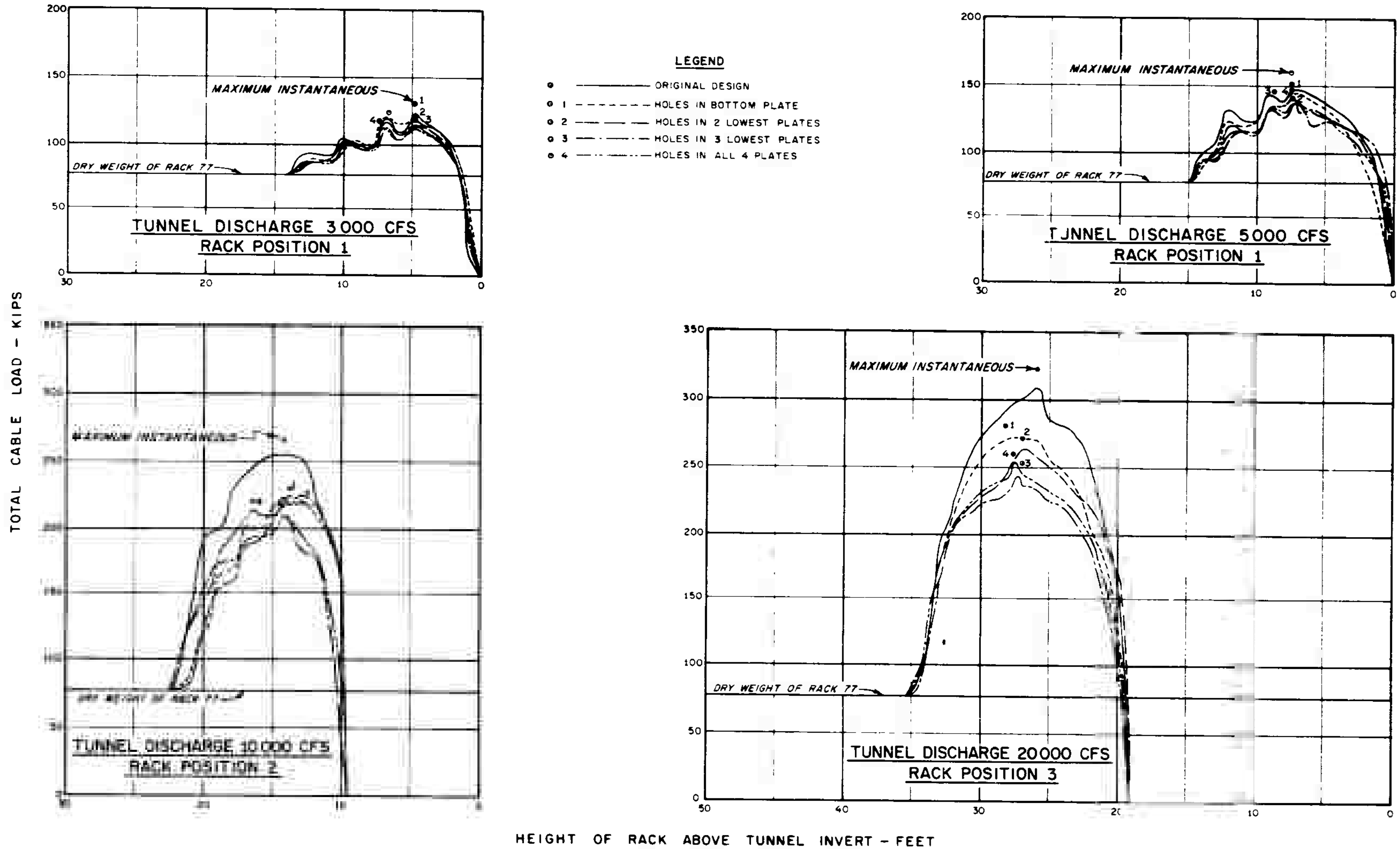
EFFECTS OF CLOSURE RACK LOWERING SPEED

NOTES

1. DETAILS OF CLOSURE RACKS ARE SHOWN ON PLATE 32.
2. PATTERNS OF HOLES IN HORIZONTAL PLATES ARE SHOWN ON PLATE 34
3. CURVES ARE PLOTS OF AVERAGE LOADING
4. MODEL RACK WAS LOWERED MANUALLY AT THE SPEED OF 20 F.P.M.

CABLE LOADINGS

EFFECTS OF HOLE PATTERNS IN HORIZONTAL PLATES AND CLOSURE RACK LOWERING SPEED



NOTES

1 DETAILS OF CLOSURE RACKS ARE SHOWN ON PLATE 32

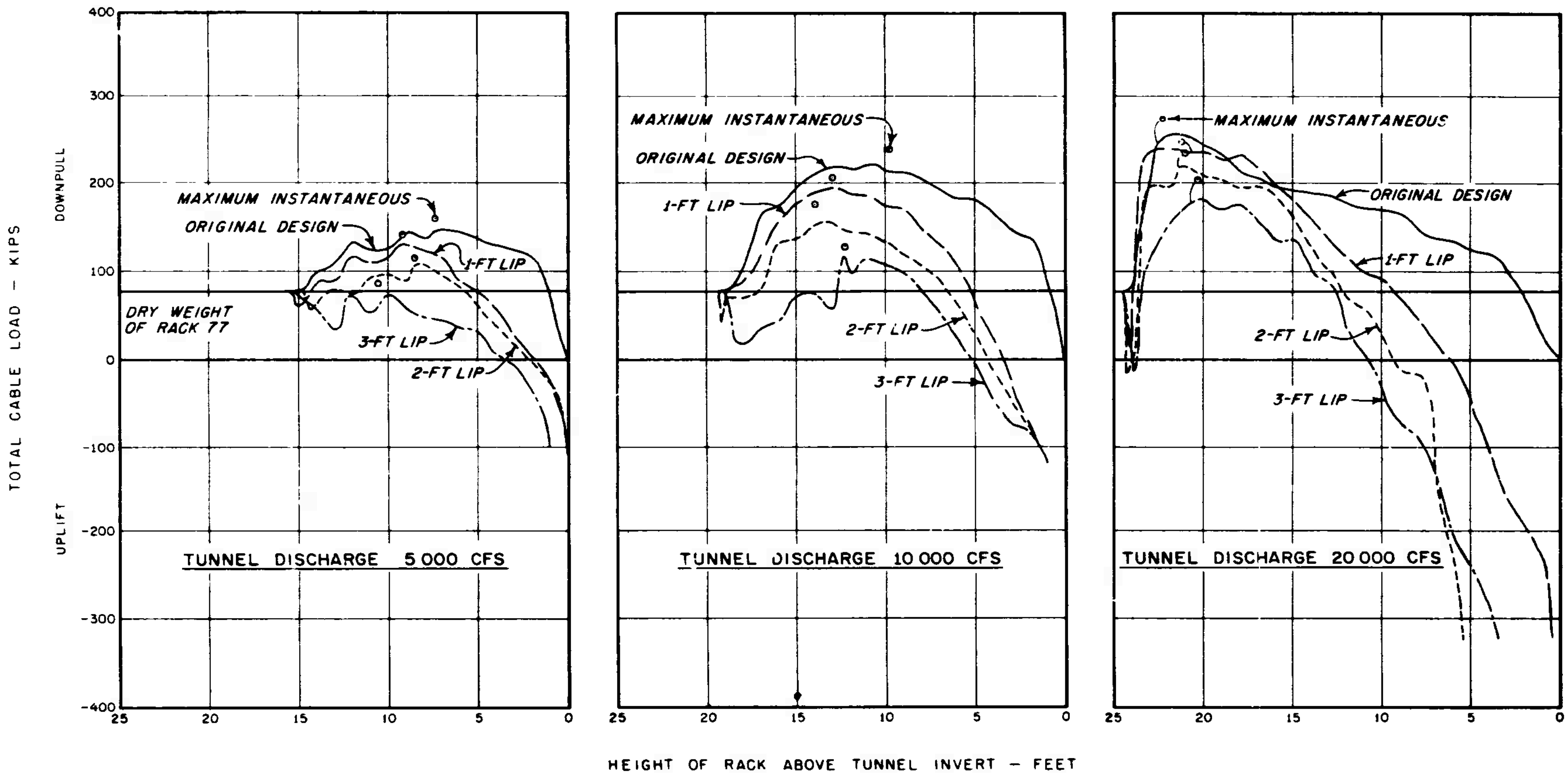
2 PATTERNS OF HOLES IN HORIZONTAL PLATES ARE SHOWN ON PLATE 34

3 CURVES ARE PLOTS OF AVERAGE LOADING

PATTERN 2 HOLES IN HORIZONTAL PLATES

CABLE LOADS ON TUNNEL CLOSURE RACKS

ORIGINAL DESIGN; LOWERING SPEED 2 FPM

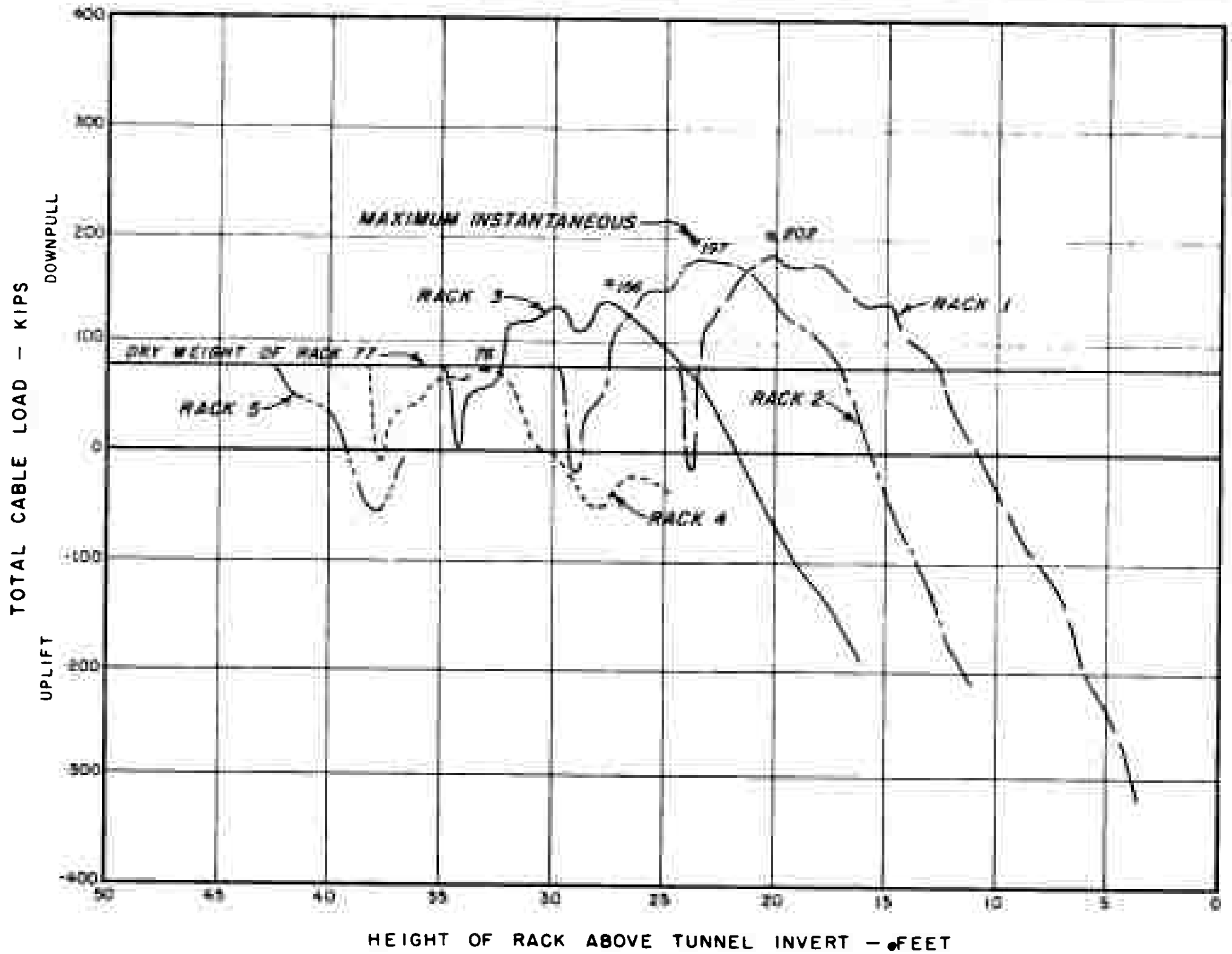


NOTES

1. DETAILS OF CLOSURE RACKS ARE SHOWN ON PLATE 32.
2. CURVES ARE PLOTS OF AVERAGE LOADING.
3. HEIGHT ABOVE INVERT MEASURED TO LOWEST POINT ON RACK.

CABLE LOADINGS

EFFECTS OF LIP ON CLOSURE RACK IN POSITION I
ORIGINAL DESIGN; LOWERING SPEED 2 FPM



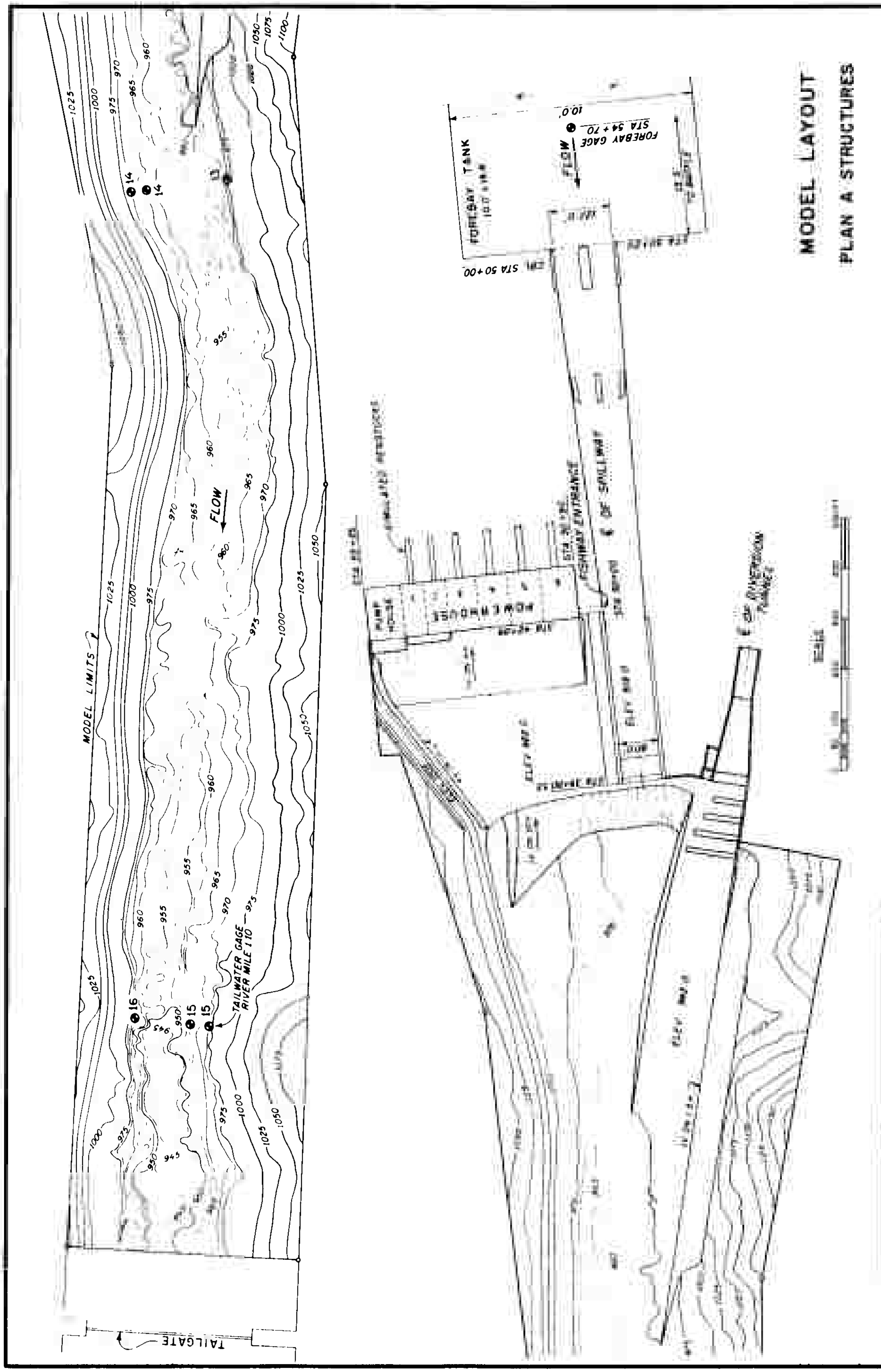
NOTES

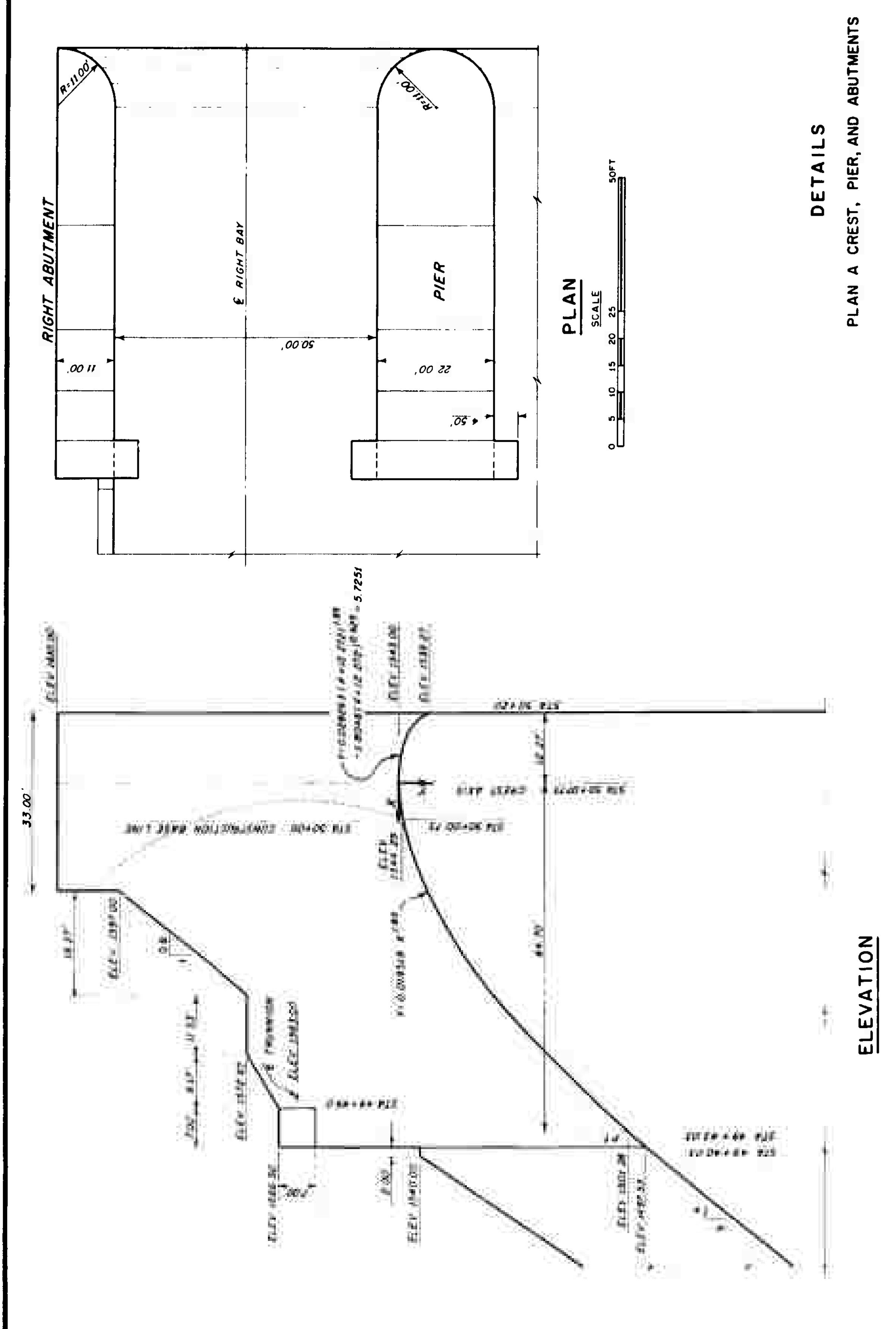
1. CURVES ARE PLOTS OF AVERAGE LOADING.
2. HEIGHT ABOVE INVERT MEASURED TO LOWEST POINT ON RACK.
3. RACK IN POSITION 1.

CABLE LOADINGS

ORIGINAL DESIGN CLOSURE RACK WITH 3-FT LIP

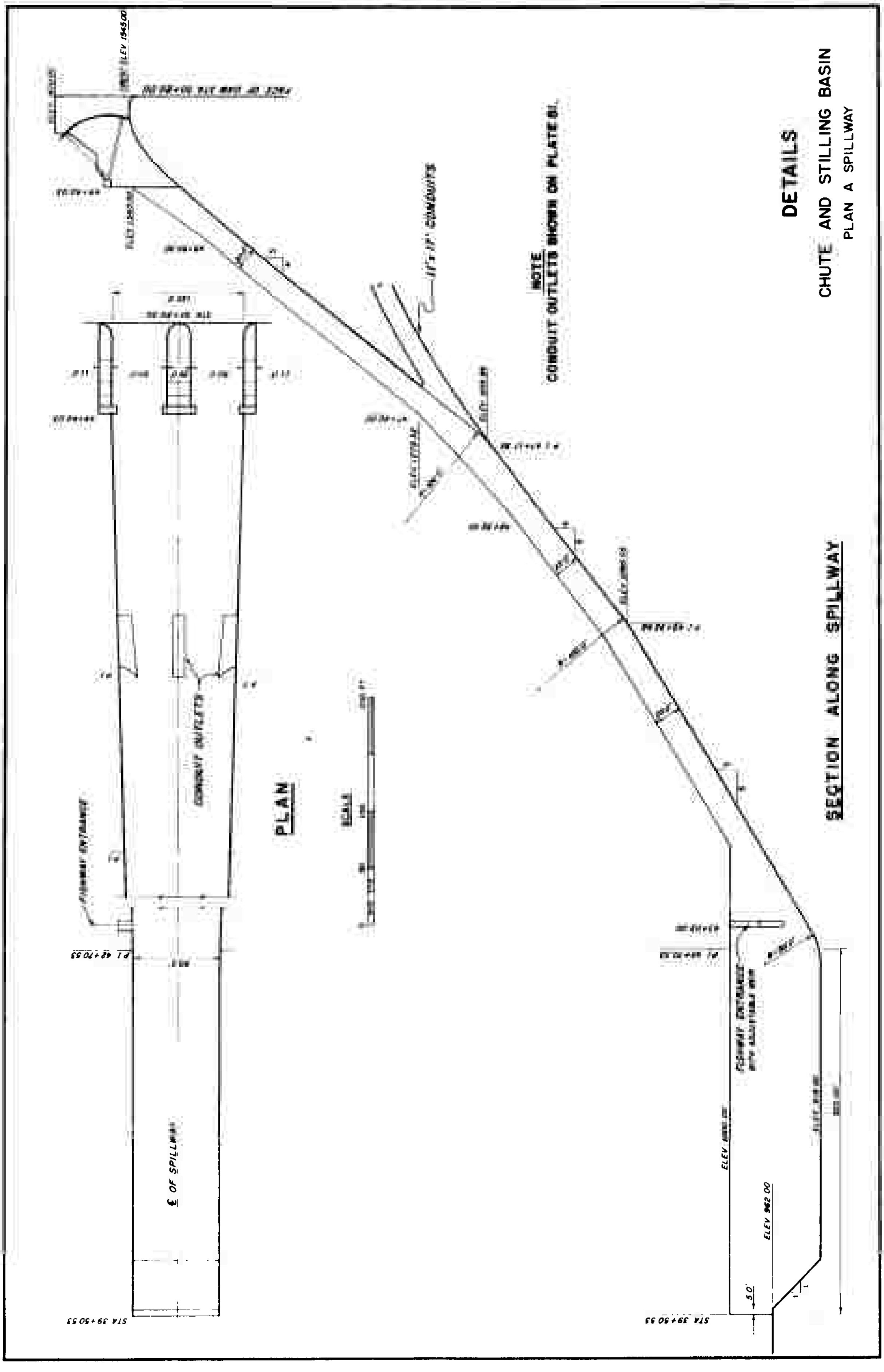
TUNNEL DISCHARGE 20 000 CFS
LOWERING SPEED 2 FPM

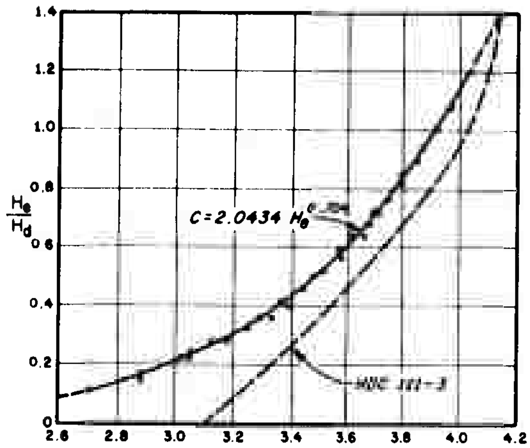

MODEL LAYOUT
PLAN A STRUCTURES
MODEL LIMITS
FLOW
FOREBAY TANK
FOREBAY GAGE
STA 54+70
STA 50+00
POWERHOUSE
FISHWAY ENTRANCE
℄ OF SPILLWAY
℄ OF DIVERSION TUNNEL
TAILWATER GAGE
RIVER MILE 1.10
TAILGATE
14
14
15
15
16



DETAILS

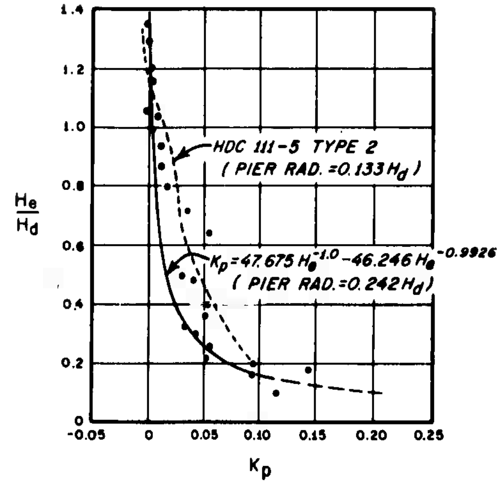
PLAN A CREST, PIER, AND ABUTMENTS


DETAILS
CHUTE AND STILLING BASIN
PLAN A SPILLWAY
SECTION ALONG SPILLWAY
NOTE
CONDUIT OUTLETS SHOWN ON PLATE 51.
11' x 17' CONDUITS
PLAN
CONDUIT OUTLETS
FISHWAY ENTRANCE
℄ OF SPILLWAY
SCALE
PI 42+70.53
STA 39+50.53
FISHWAY ENTRANCE WITH ADJUSTABLE WEIR
ELEV 962.00
5.0'



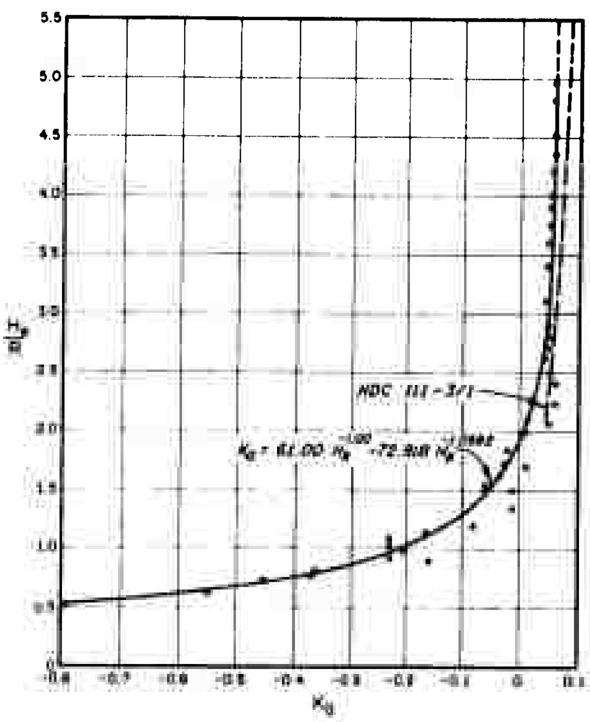
CREST DISCHARGE COEFFICIENT

$$C = \frac{Q}{LH_e^{3/2}}$$



PIER CONTRACTION COEFFICENT

$$Q = C(L-2K_p H_e)\ H_e^{3/2}$$



ABUTMENT CONTRACTION COEFFICIENT

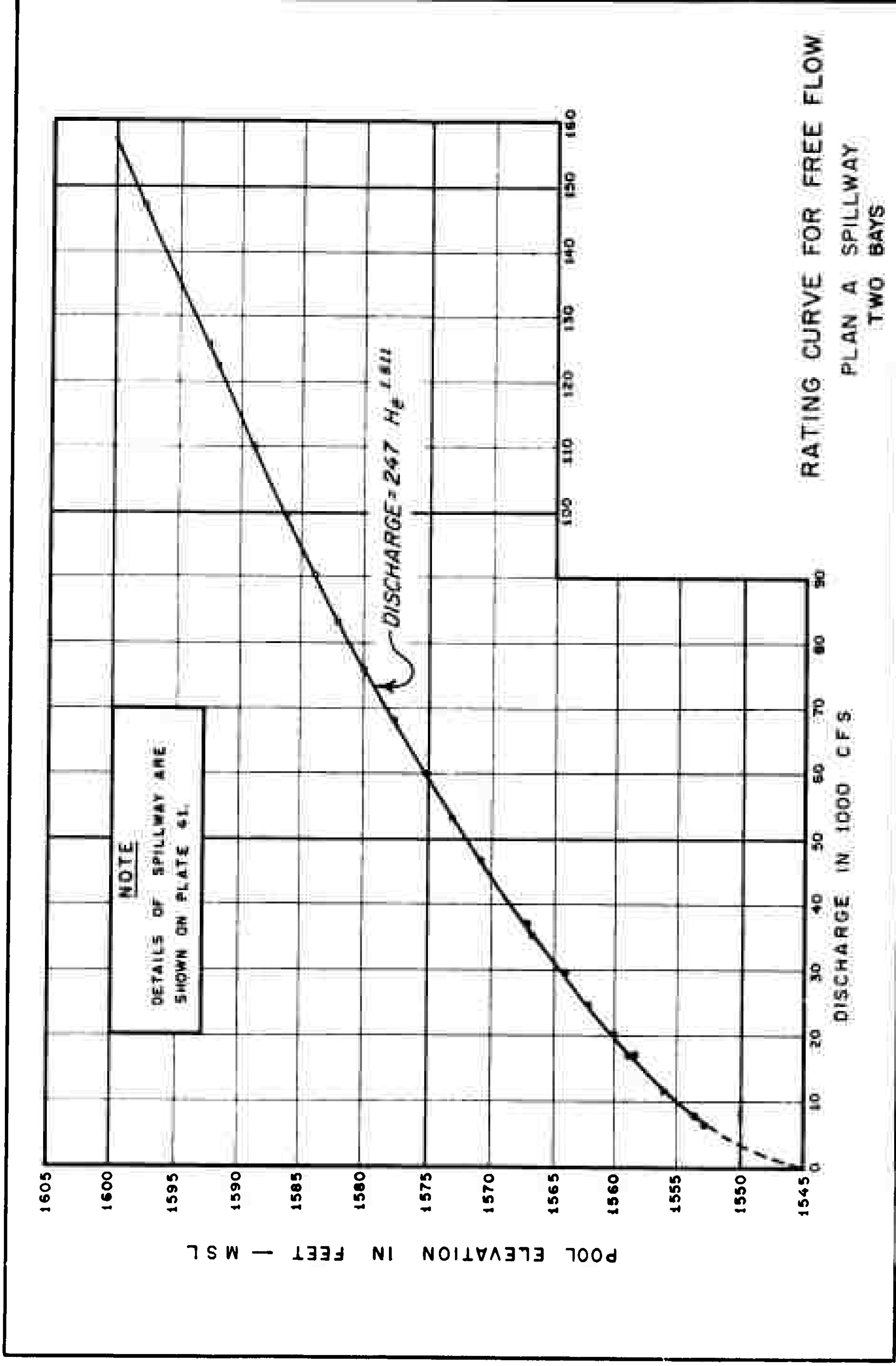
$$Q = C(L-2K_a H_e)\ H_e^{3/2}$$

LEGEND

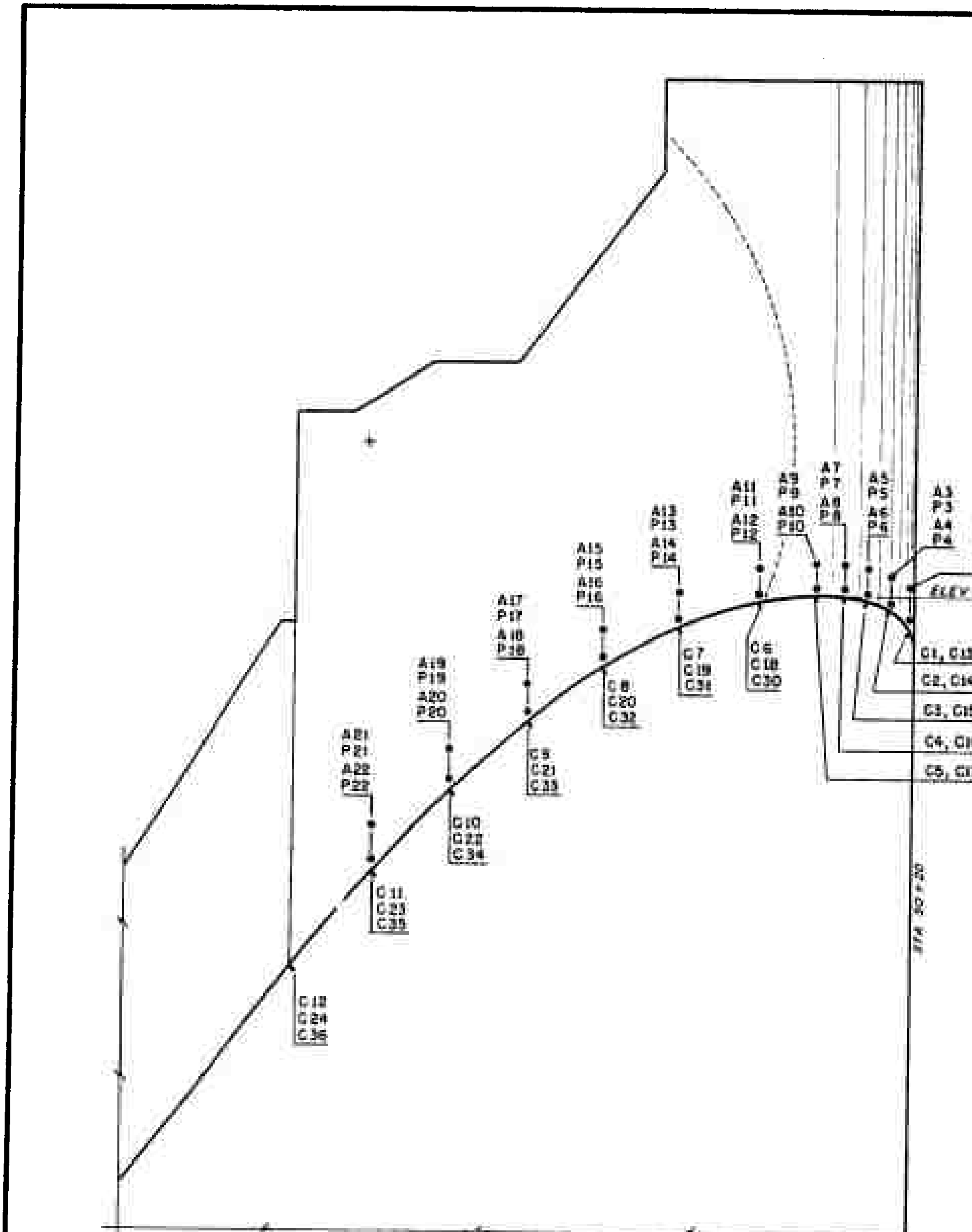
Q = DISCHARGE, CFS
C = CREST DISCHARGE COEFFICIENT
L = NET LENGTH OF CREST, FT
H_e = TOTAL HEAD ON CREST, FT
H_d = DESIGN HEAD ON CREST, 45.402 FT
K_a = ABUTMENT CONTRACTION COEFFICIENT
K_p = PIER CONTRACTION COEFFICIENT
R = RADIUS OF ABUTMENT, 11 FT

DISCHARGE COEFFICIENTS FOR FREE FLOW

PLAN A SPILLWAY



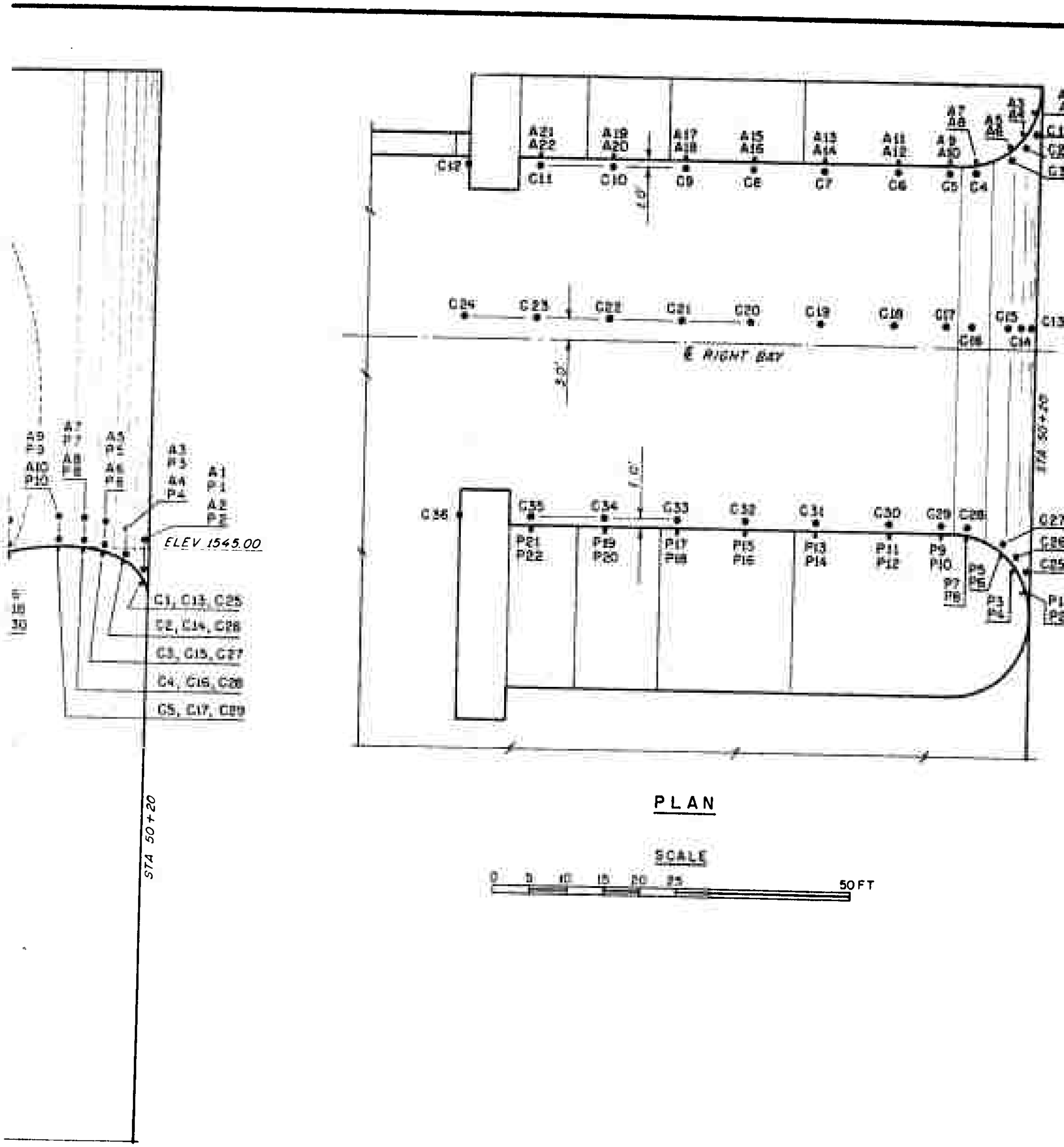
RATING CURVE FOR FREE FLOW
PLAN A SPILLWAY
TWO BAYS
NOTE
DETAILS OF SPILLWAY ARE SHOWN ON PLATE 41.
DISCHARGE = 247 $H_e^{1.611}$
DISCHARGE IN 1000 CFS
POOL ELEVATION IN FEET — M S L



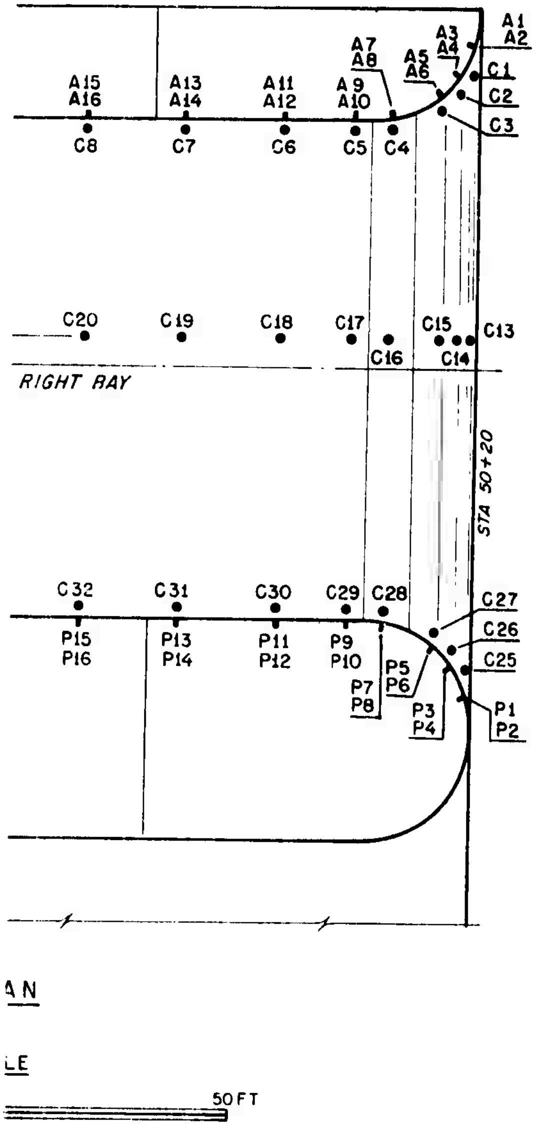
ELEVATION

Plate 45

1


A9 P9
A10 P10
A7 P7
A8 P8
A5 P5
A6 P6
A3 P3
A4 P4
A1 P1
A2 P2
ELEV 1545.00
C1, C13, C25
C2, C14, C26
C3, C15, C27
C4, C16, C28
C5, C17, C29
STA 50+20
A21 A22
A19 A20
A17 A18
A15 A16
A13 A14
A11 A12
A9 A10
A7 A8
A5 A6
A3 A4
C12
C11
C10
C9
C8
C7
C6
C5
C4
C24
C23
C22
C21
C20
C19
C18
C17
C16
C15
C14
C13
℄ RIGHT BAY
STA 50+20
C36
C35
C34
C33
C32
C31
C30
C29
C28
C27
C26
C25
P21 P22
P19 P20
P17 P18
P15 P16
P13 P14
P11 P12
P9 P10
P7 P8
P5 P6
P3 P4
P1 P2
SCALE
0 5 10 15 20 25 50 FT

PLAN

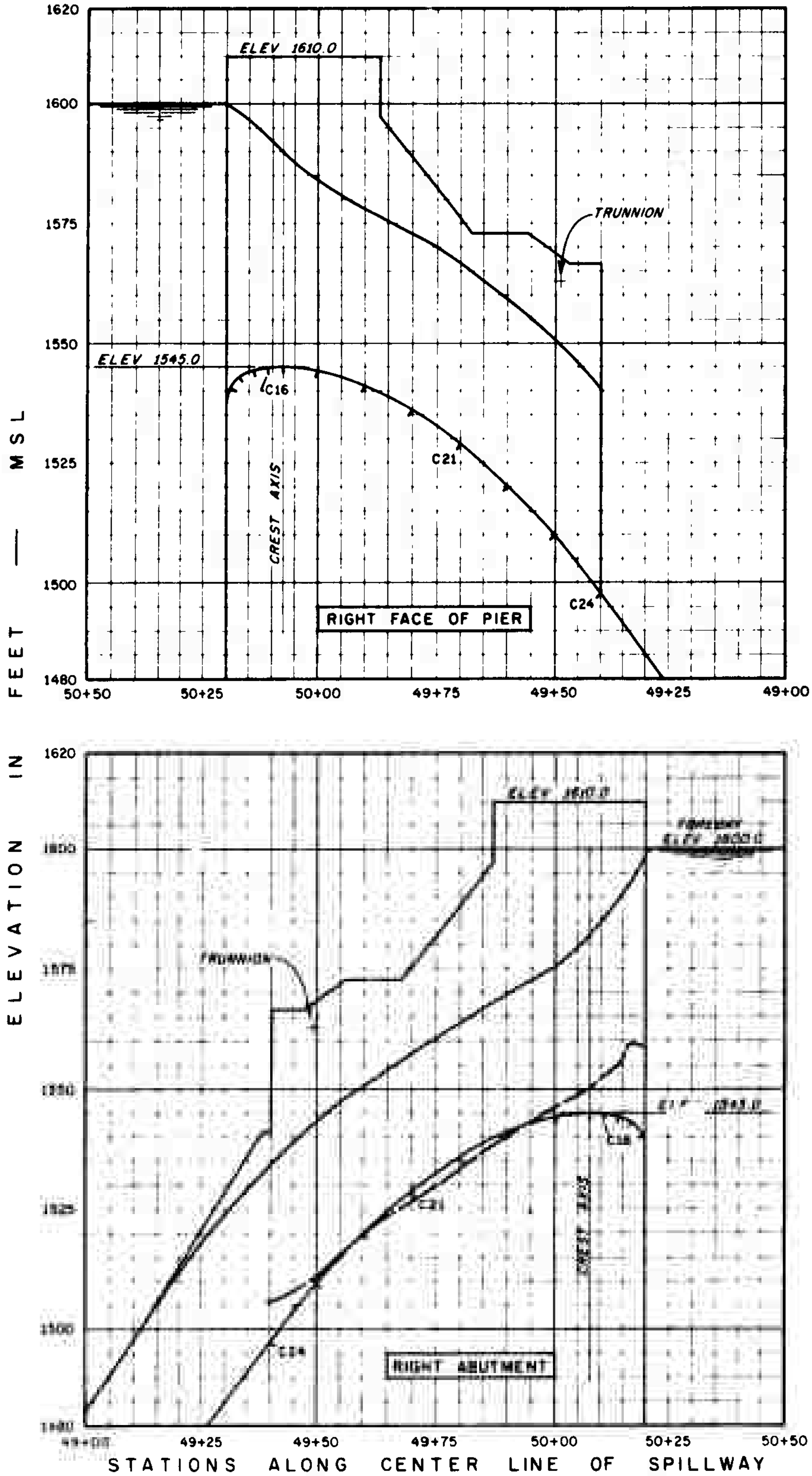


PIEZOMETER LOCATIONS		
PIEZO NO.	STATION	ELEVATION
C1, C13, C25	50+19.50	1540.43
C2, C14, C26	50+17.00	1542.64
C3, C15, C27	50+14.00	1544.02
C4, C16, C28	50+11.00	1544.75
C5, C17, C29	50+07.73	1545.00
C6, C18, C30	50+00.00	1544.14
C7, C19, C31	49+90.00	1541.02
C8, C20, C32	49+80.00	1535.88
C9, C21, C33	49+70.00	1528.89
C10, C22, C34	49+60.00	1520.10
C11, C23, C35	49+50.00	1509.60
C12, C24, C36	49+40.00	1497.43
A1, P1	50+19.50	1544.43
A2, P2	50+19.50	1541.43
A3, P3	50+17.00	1546.64
A4, P4	50+17.00	1543.64
A5, P5	50+14.00	1548.02
A6, P6	50+14.00	1545.02
A7, P7	50+11.00	1548.75
A8, P8	50+11.00	1545.75
A9, P9	50+07.73	1549.00
A10, P10	50+07.73	1546.00
A11, P11	50+00.00	1548.14
A12, P12	50+00.00	1545.14
A13, P13	49+90.00	1545.02
A14, P14	49+90.00	1542.02
A15, P15	49+80.00	1539.88
A16, P16	49+80.00	1536.88
A17, P17	49+70.00	1532.89
A18, P18	49+70.00	1529.89
A19, P19	49+60.00	1524.10
A20, P20	49+60.00	1521.10
A21, P21	49+50.00	1513.60
A22, P22	49+50.00	1510.60

PIEZOMETER LOCATIONS

PLAN A CREST, PIER AND ABUTMENTS

3 of 3



LEGEND

——— WATER-SURFACE PROFILE ALONG RIGHT ABUTMENT OR PIER

— — — PRESSURE PROFILE AT CENTER LINE OF RIGHT BAY

NOTE

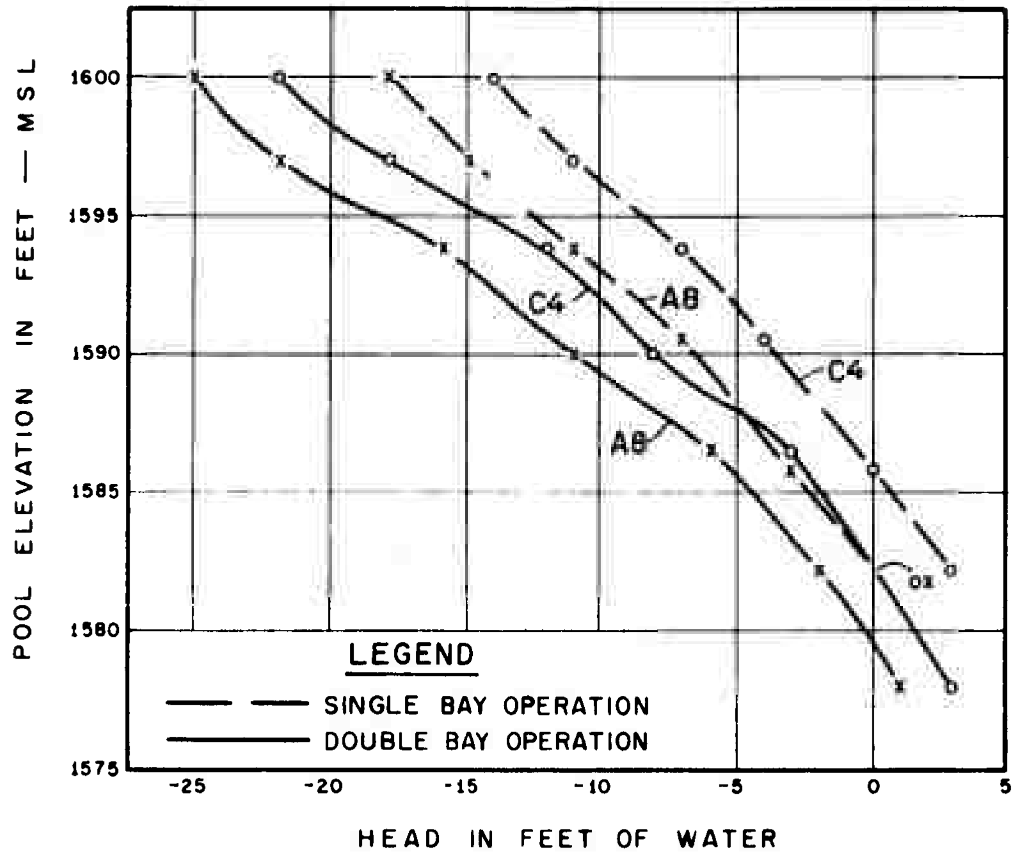
DETAILS OF SPILLWAY ARE SHOWN ON PLATE 41

WATER-SURFACE AND PRESSURE PROFILES

PLAN A SPILLWAY

FREE FLOW THROUGH BOTH BAYS

SPILLWAY DISCHARGE 157 200 CFS

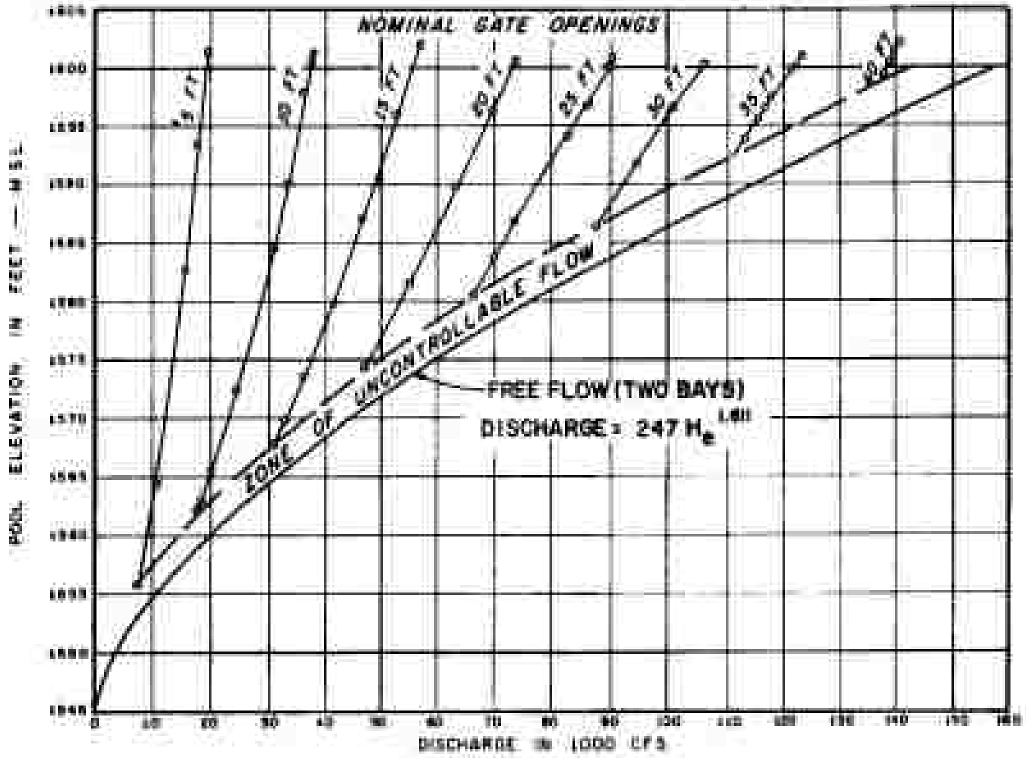


NOTES

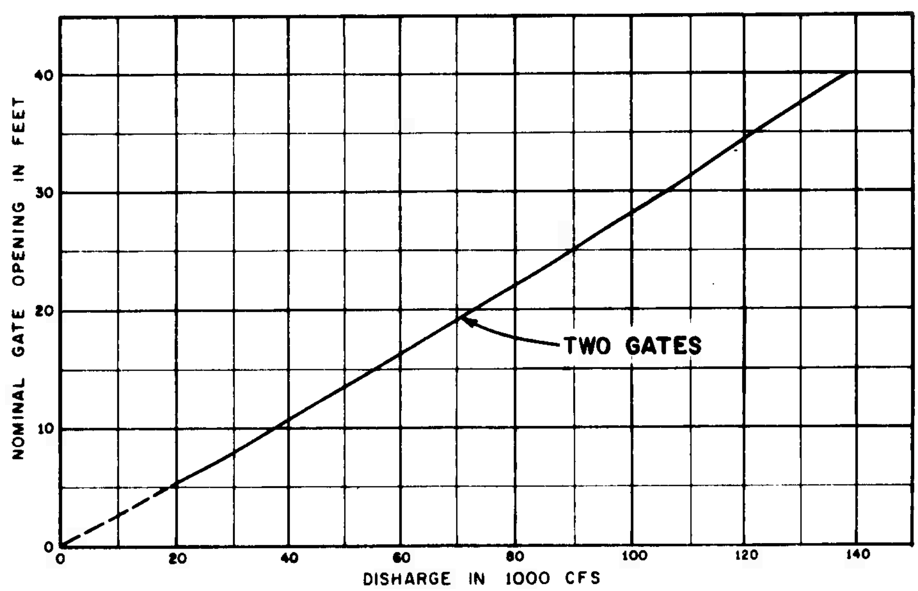
1. SINGLE BAY DISCHARGE = $83.1\ H_e^{1.708}$
   DOUBLE BAY DISCHARGE = $247\ H_e^{1.611}$
2. PIEZOMETER LOCATIONS ARE SHOWN ON PLATE 45.

PRESSURES AT PIEZOMETERS A8 AND C4

FREE FLOW OVER PLAN A SPILLWAY



POOL ELEVATIONS 1545 TO 1602



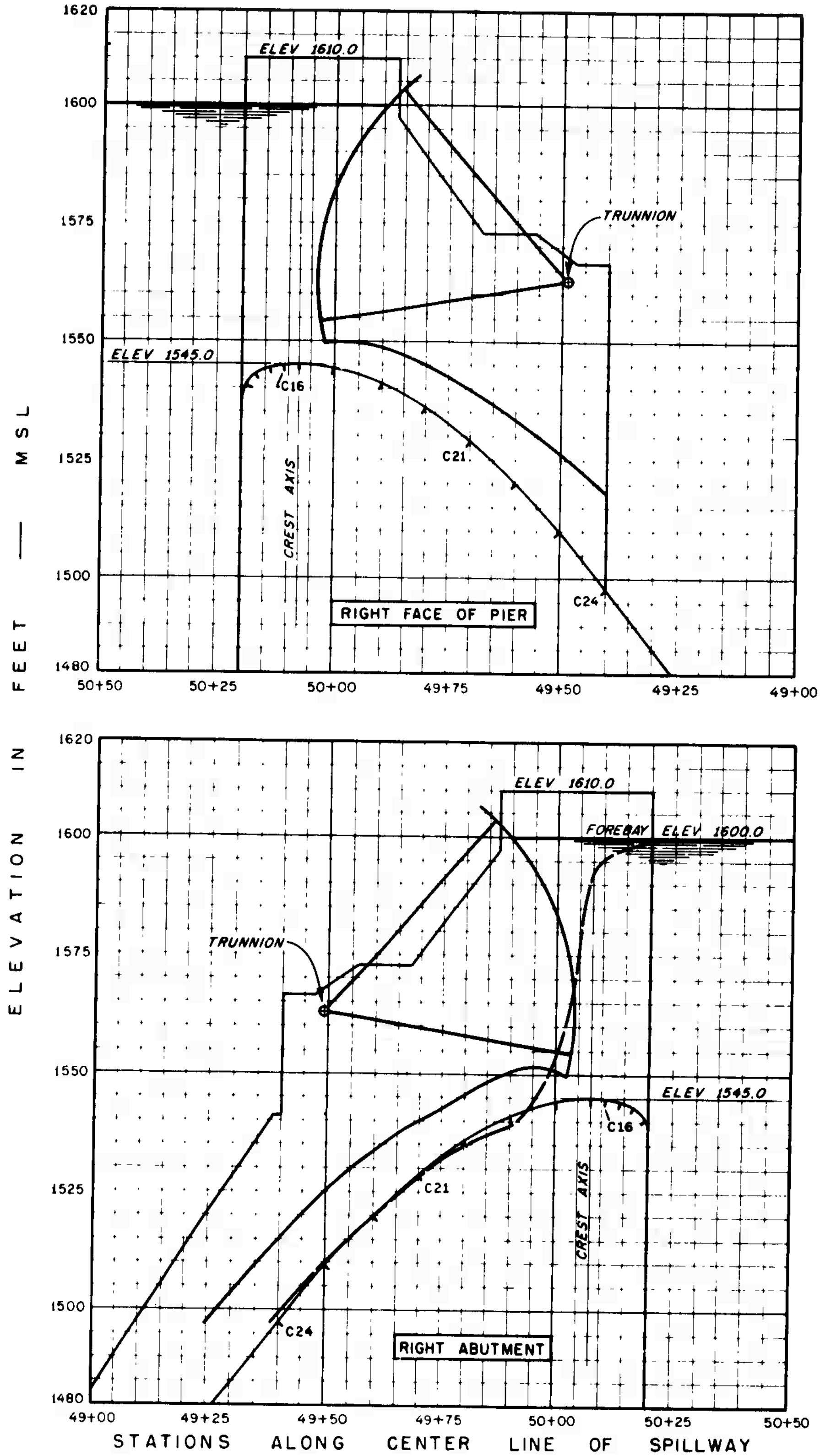
POOL ELEVATION 1600

NOTE

DETAILS OF SPILLWAY ARE SHOWN ON PLATE 41.

RATING CURVES FOR GATED FLOW

PLAN A SPILLWAY



LEGEND

——— WATER-SURFACE PROFILE ALONG RIGHT ABUTMENT OR PIER

— — PRESSURE PROFILE AT CENTER LINE OF RIGHT BAY

NOTE

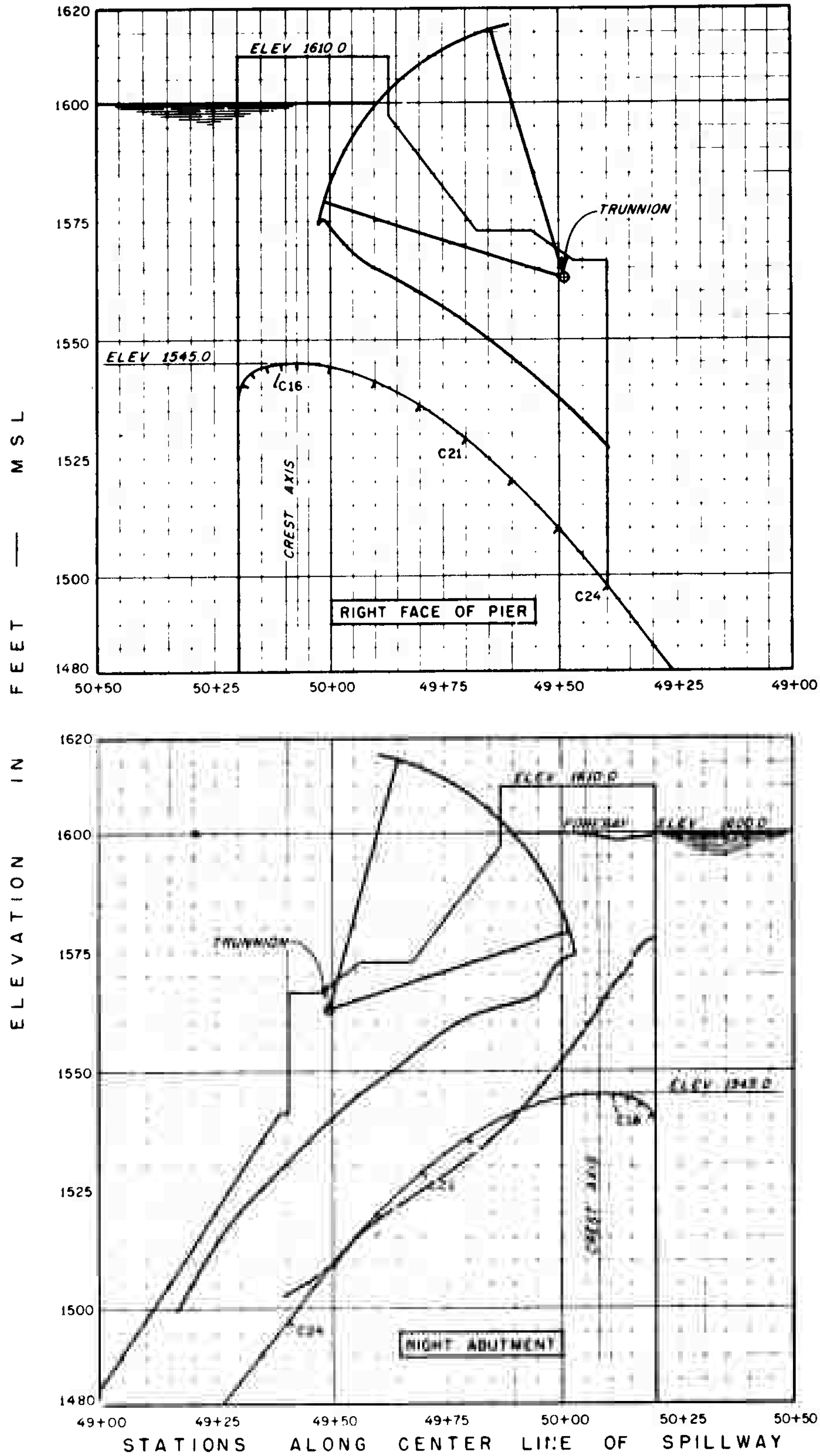
DETAILS OF SPILLWAY ARE SHOWN ON PLATE 41

WATER-SURFACE AND PRESSURE PROFILES

PLAN A SPILLWAY

BOTH GATES OPEN 5.0 FT

SPILLWAY DISCHARGE 19 000 CFS



LEGEND

——— WATER-SURFACE PROFILE ALONG RIGHT ABUTMENT OR PIER

— — — PRESSURE PROFILE AT CENTER LINE OF RIGHT BAY

NOTE

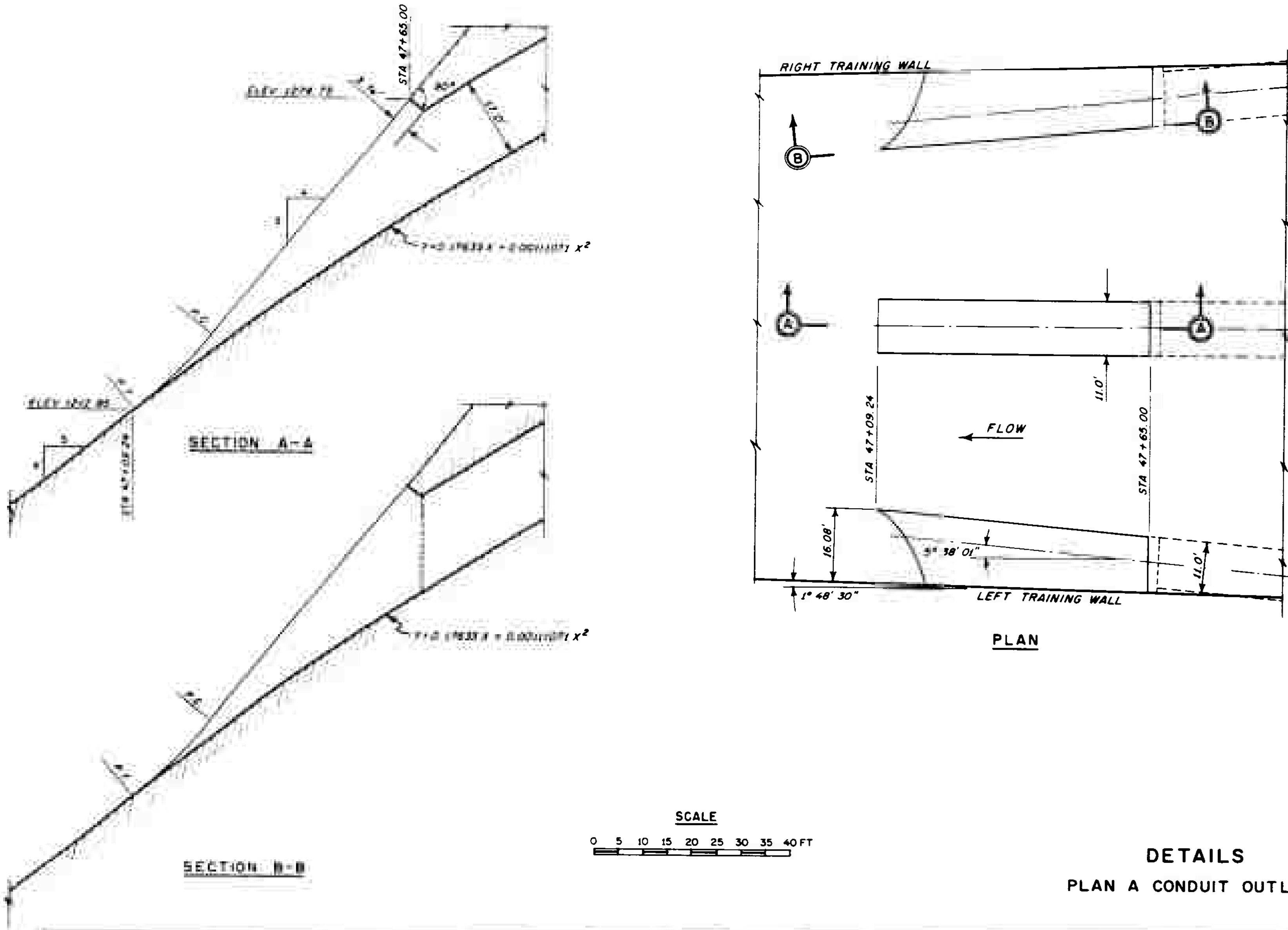
DETAILS OF SPILLWAY ARE SHOWN ON PLATE 41

WATER-SURFACE AND PRESSURE PROFILES

PLAN A SPILLWAY

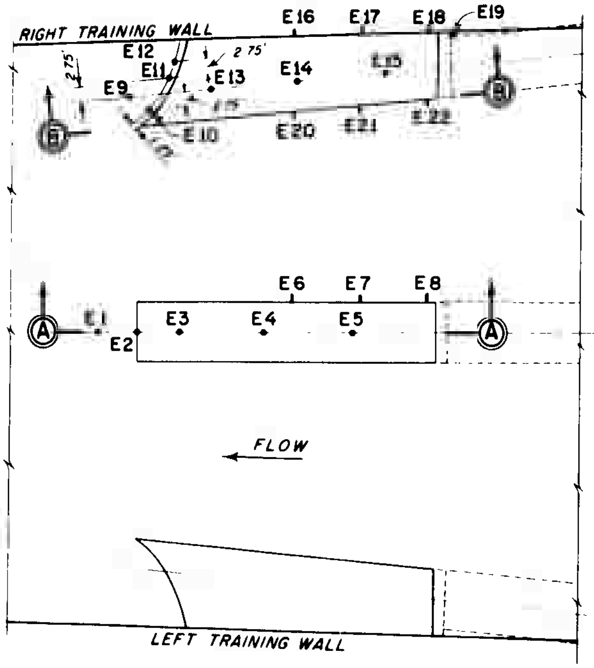
BOTH GATES OPEN 30.0 FT

SPILLWAY DISCHARGE 106 000 CFS



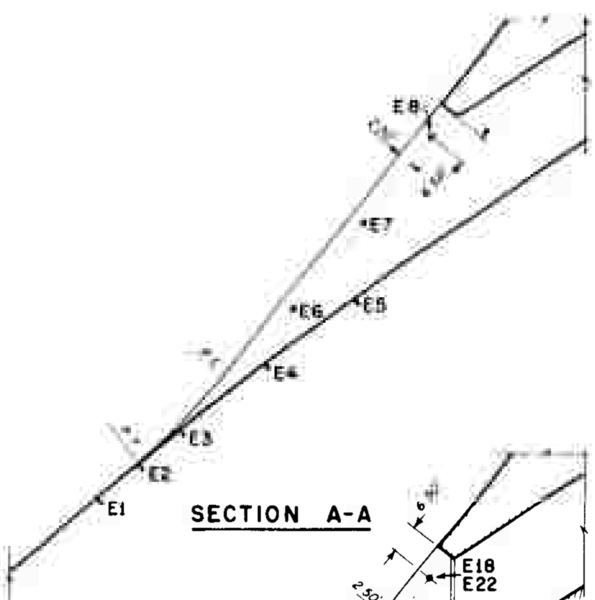
DETAILS

PLAN A CONDUIT OUTLETS

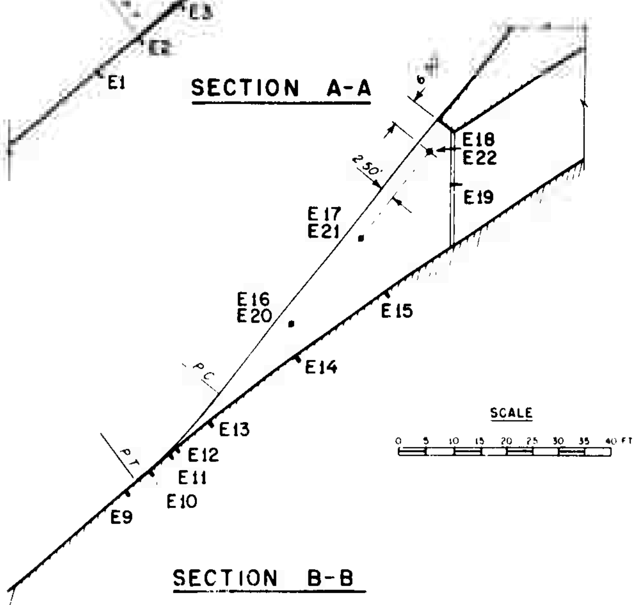


PLAN

PIEZOMETER NO.	STATION	ELEVATION
E 1	47+01 4	1206.7
E 2	47+09.2	1213 0
E 3	47+17 1	1219 2
E 4	47+33.0	1231 3
E 5	47+49 1	1243 1
E 6	47+37.9	1240 9
E 7	47+50 4	1256 5
E 8	47+62 9	1272 1
E 9	47+07 3	1211 4
E 10	47+11 3	1214 7
E 11	47+14 9	1217 9
E 12	47+16 1	1219 1
E 13	47+22 8	1224 0
E 14	47+38 7	1236 0
E 15	47+54.9	1247 6
E 16	47+37 9	1240 9
E 17	47+50 4	1256 5
E 18	47+62 9	1272 1
E 19	47+67 3	1266 8
E 20	47+38.1	1241 1
E 21	47+50 6	1256 6
E 22	47+63.0	1272.1

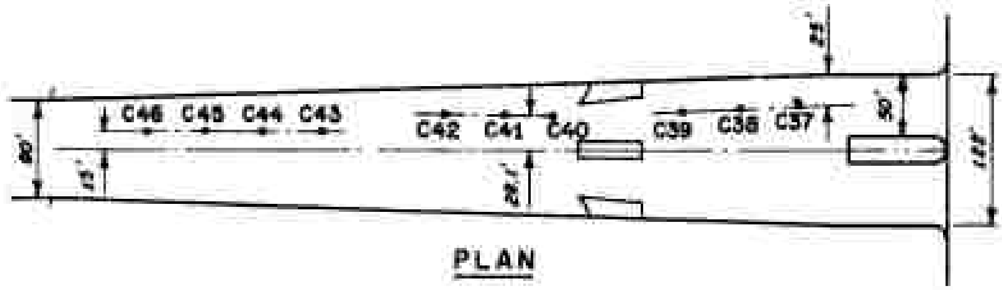


SECTION A-A



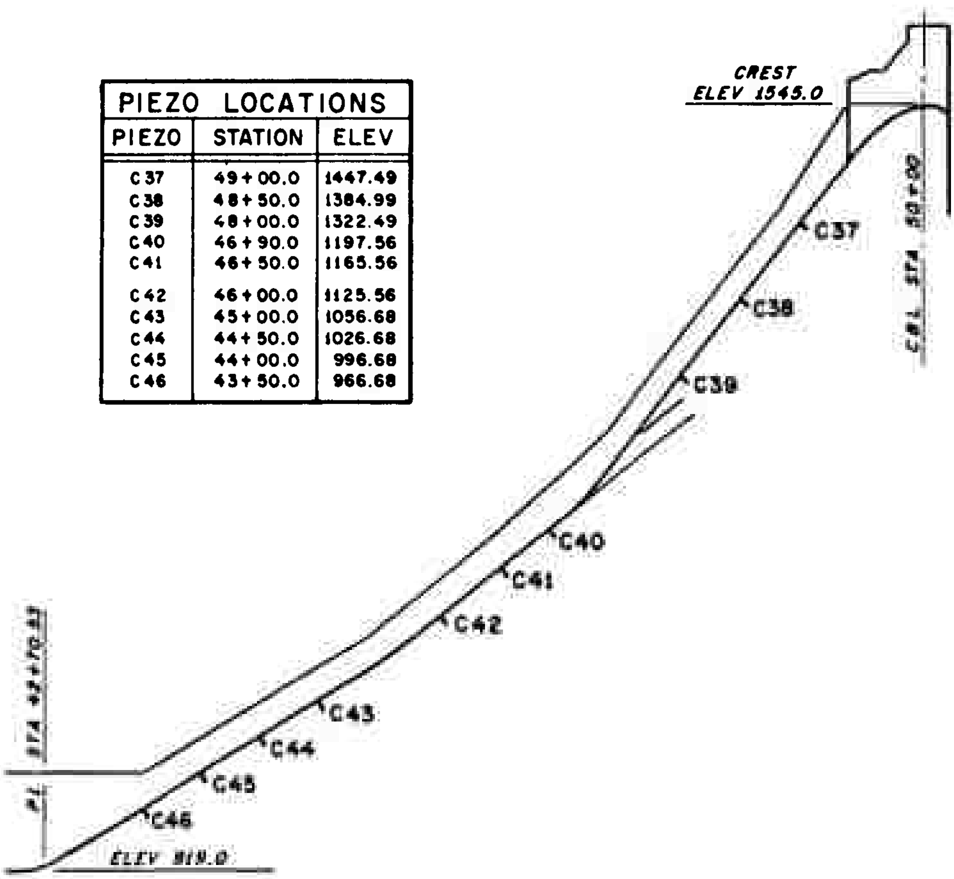
SECTION B-B

PIEZOMETER LOCATIONS
PLAN A CONDUIT OUTLETS



PLAN

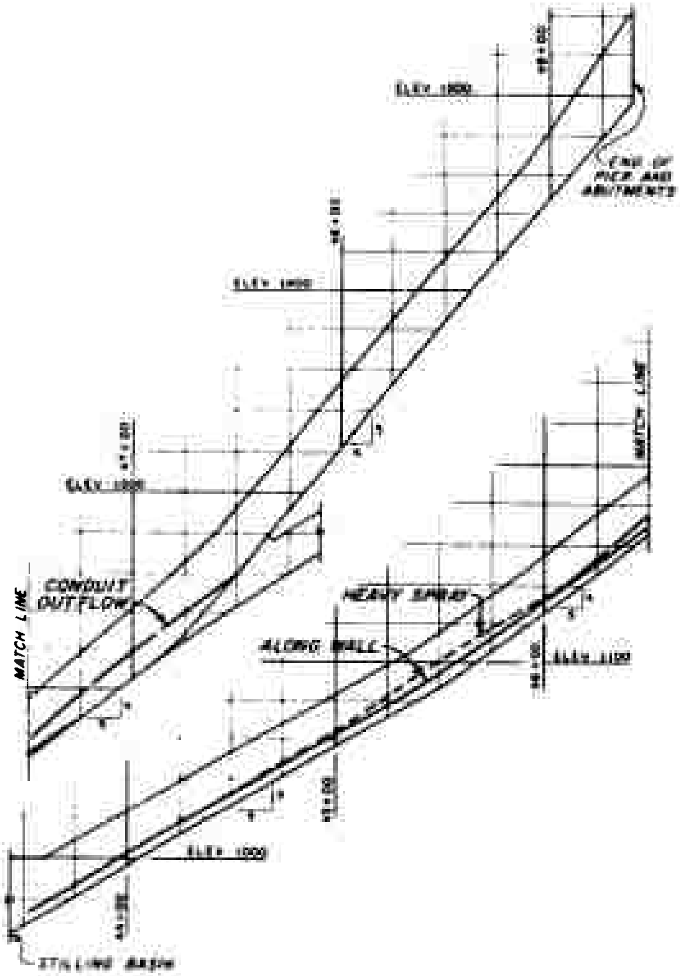
PIEZO	STATION	ELEV
C 37	49 + 00.0	1447.49
C 38	48 + 50.0	1384.99
C 39	48 + 00.0	1322.49
C 40	46 + 90.0	1197.56
C 41	46 + 50.0	1165.56
C 42	46 + 00.0	1125.56
C 43	45 + 00.0	1056.68
C 44	44 + 50.0	1026.68
C 45	44 + 00.0	996.68
C 46	43 + 50.0	966.68



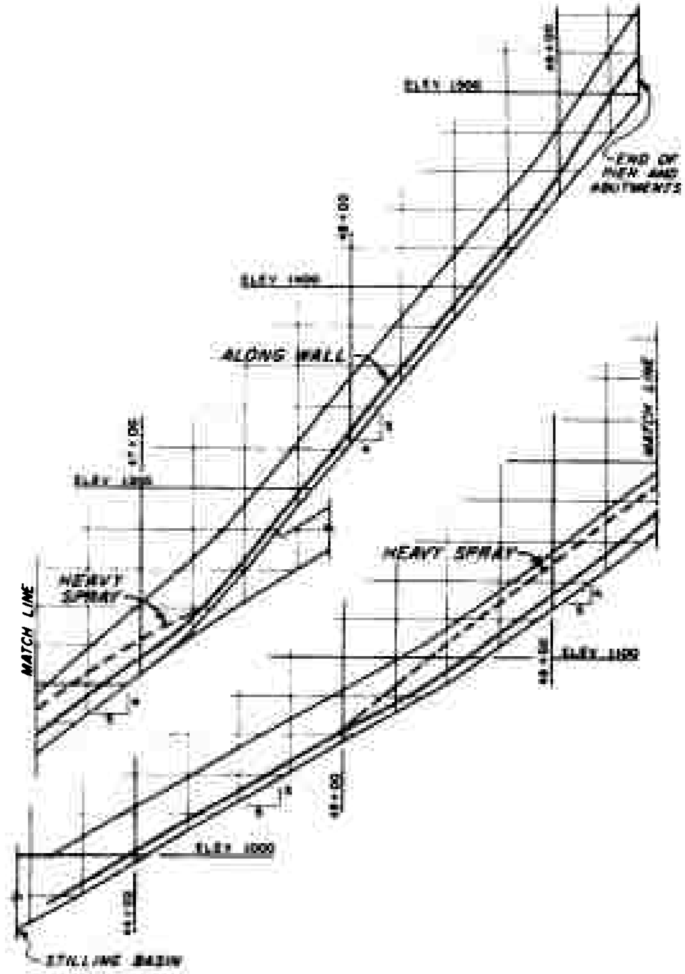
SECTION ALONG CENTER LINE

PIEZOMETER LOCATIONS

PLAN A SPILLWAY CHUTE



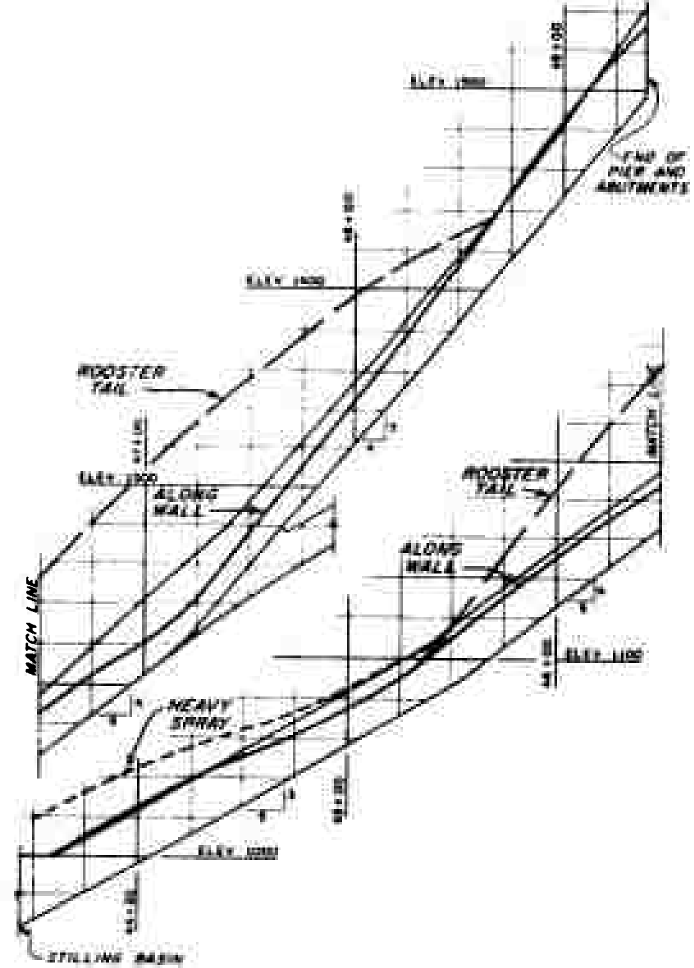
SPILLWAY CLOSED, CONDUIT DISCHARGE 41 000 CFS



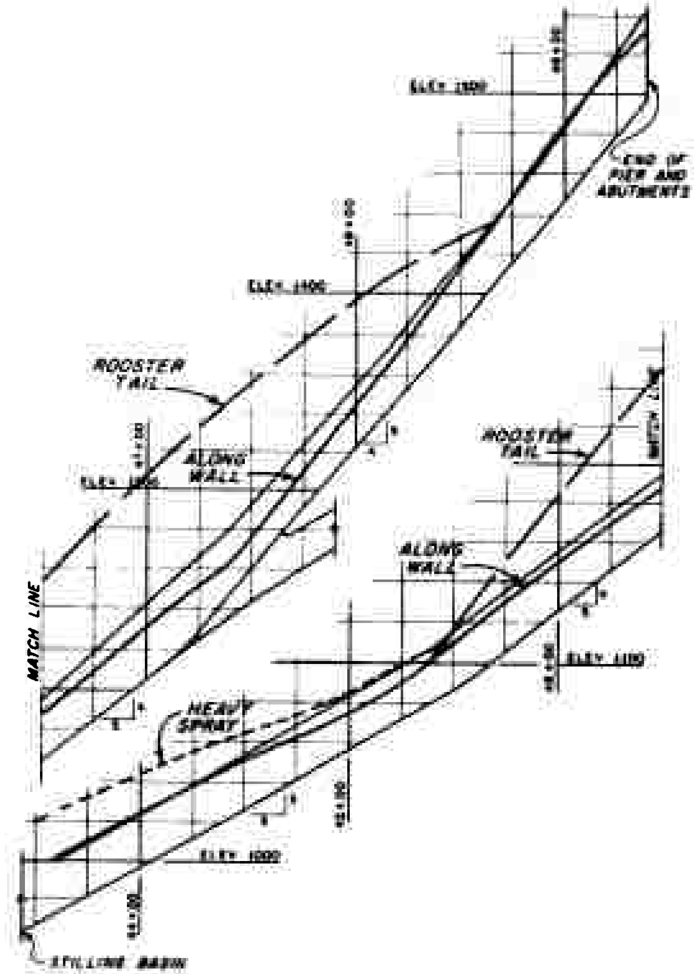
SPILLWAY DISCHARGE 40 000 CFS CONDUIT CLOSED

NOTE
CHUTE DETAILS ARE SHOWN ON PLATE 42

WATER-SURFACE PROFILES
PLAN A SPILLWAY CHUTE



CONDUIT CLOSED



CONDUIT DISCHARGE 41 000 CFS

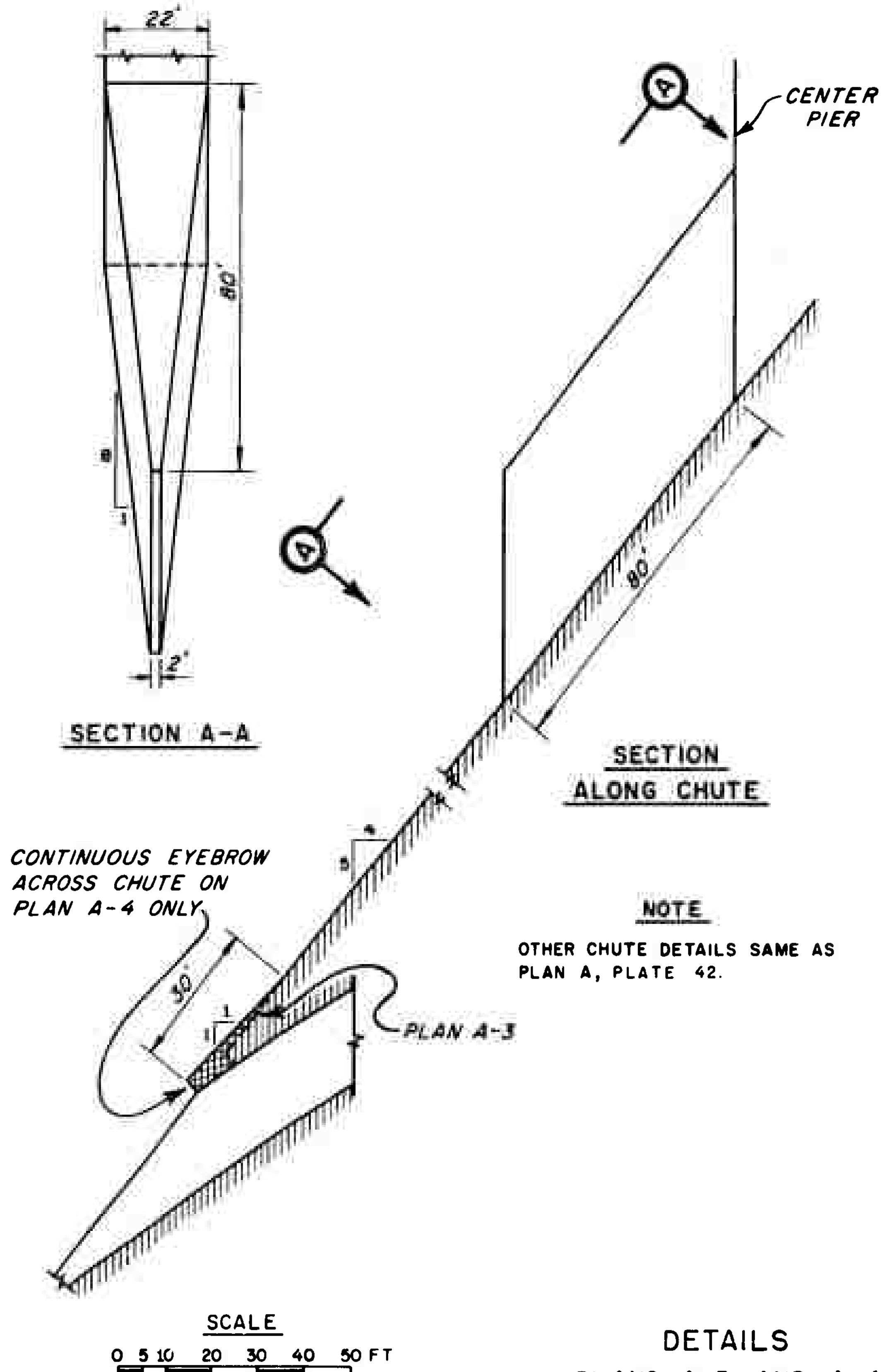
NOTE

CHUTE DETAILS ARE SHOWN ON PLATE 42.

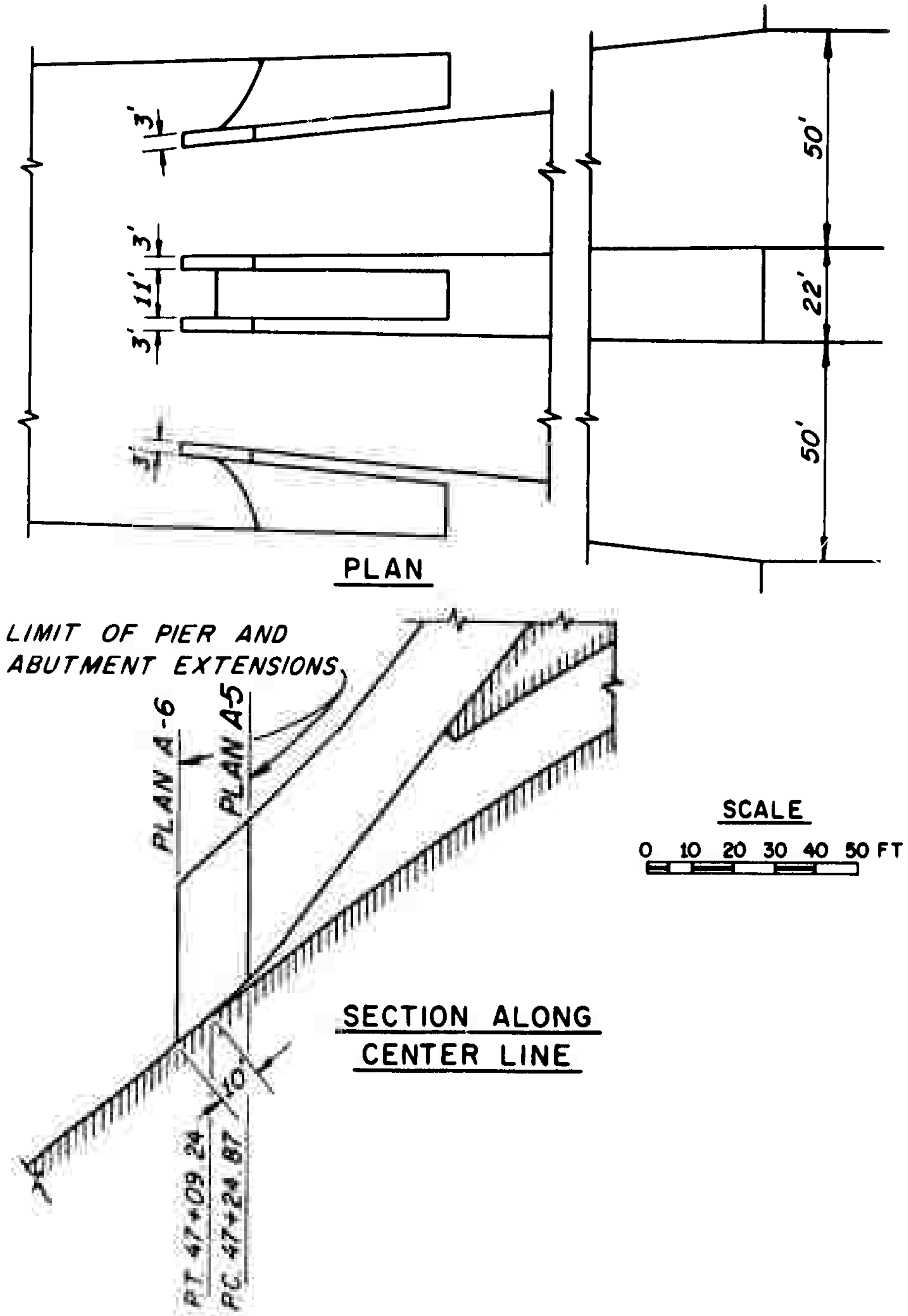
WATER-SURFACE PROFILES

PLAN A SPILLWAY CHUTE

SPILLWAY DISCHARGE 157 200 CFS



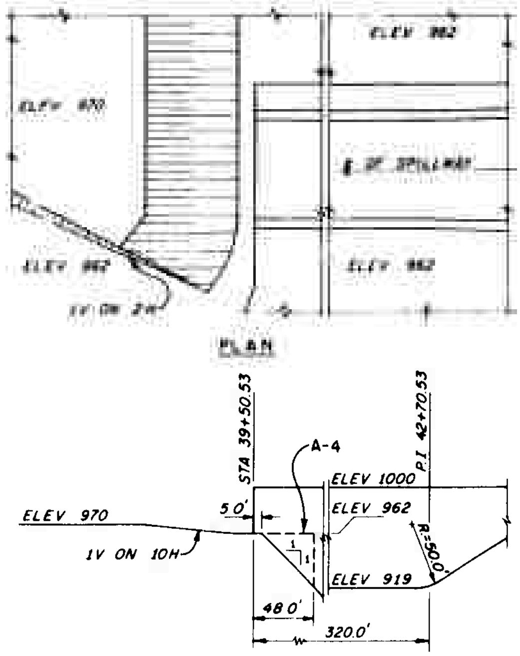
DETAILS
PLANS A-3 AND A-4
CHUTE STRUCTURES



NOTE

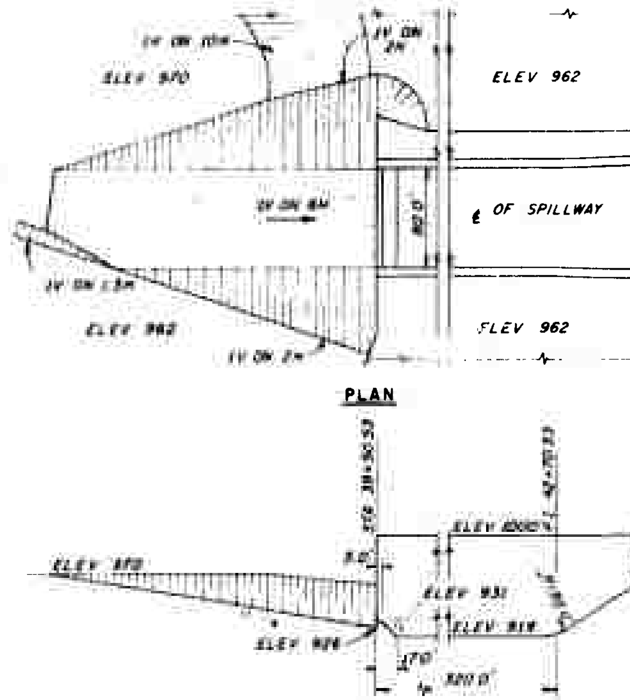
OTHER CHUTE DETAILS THE SAME AS PLAN A, PLATE 42.

DETAILS
PLANS A-5 AND A-6
CHUTE STRUCTURES



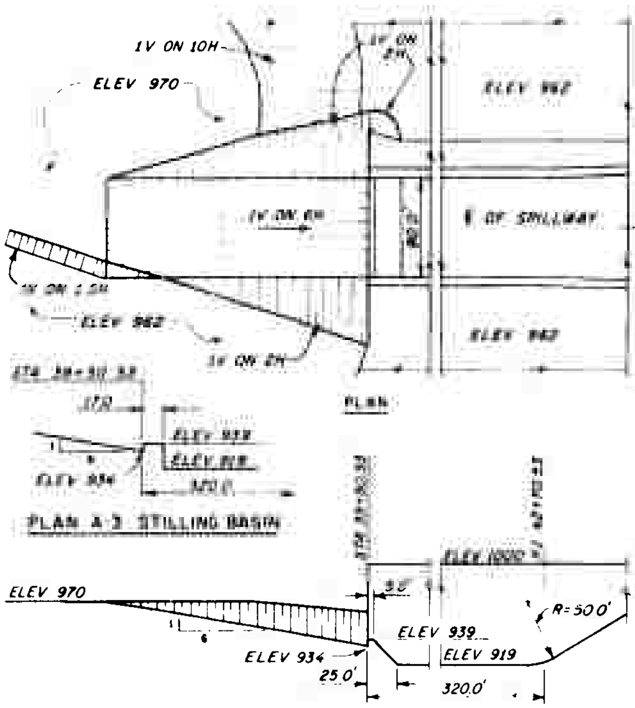
SECTION ALONG CENTER LINE OF SPILLWAY

PLANS A AND A-4



SECTION ALONG CENTER LINE OF SPILLWAY

PLAN A-1



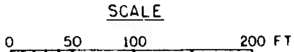
SECTION ALONG CENTER LINE OF SPILLWAY

PLANS A-2 AND A-3

NOTE

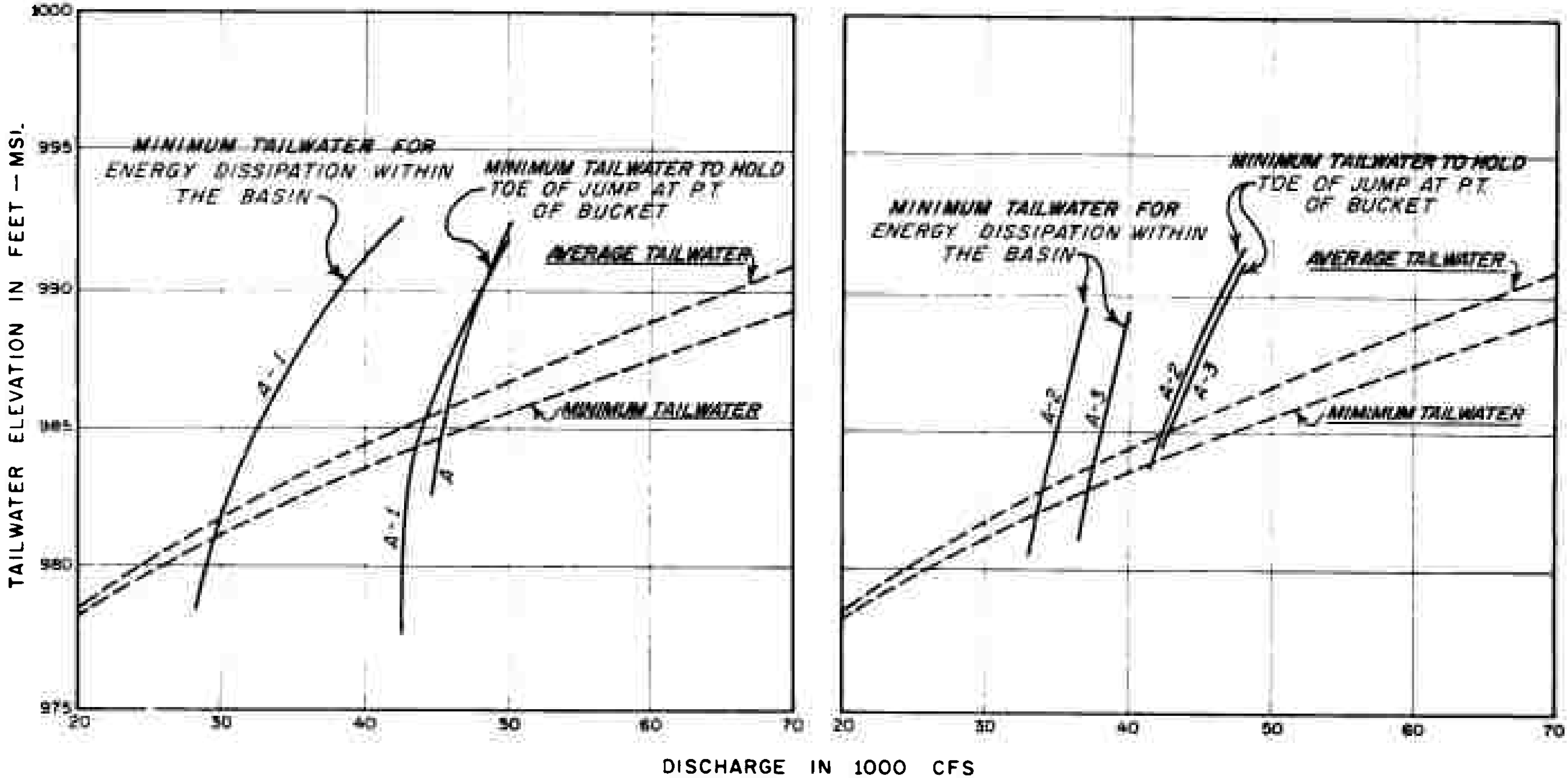
DETAILS OF SPILLWAY ARE SHOWN ON PLATES 41 AND 42

SCALE



STILLING BASIN PLANS A TO A-4

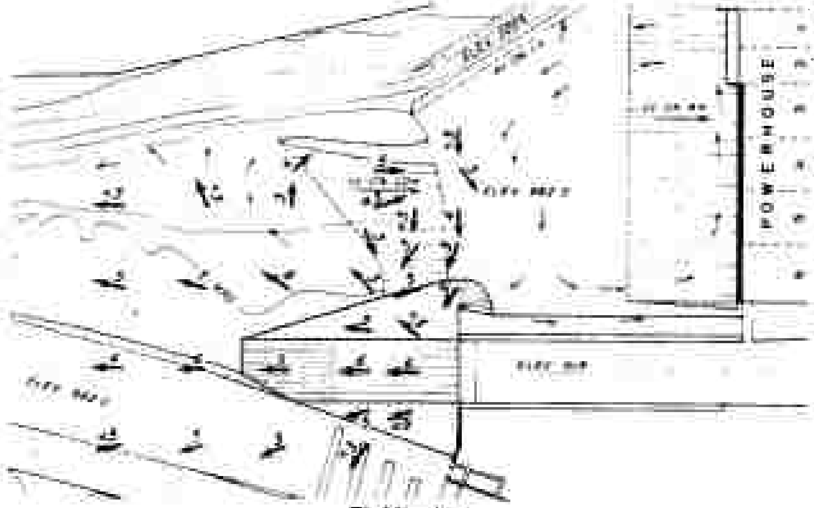
PLAN A SPILLWAY

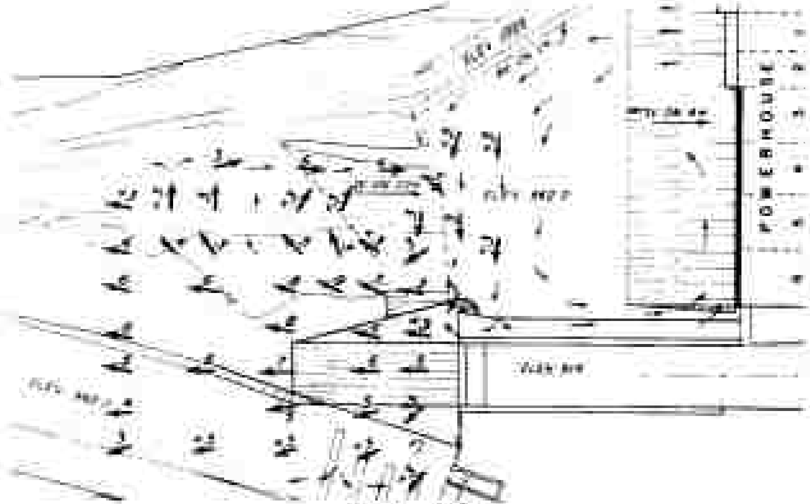


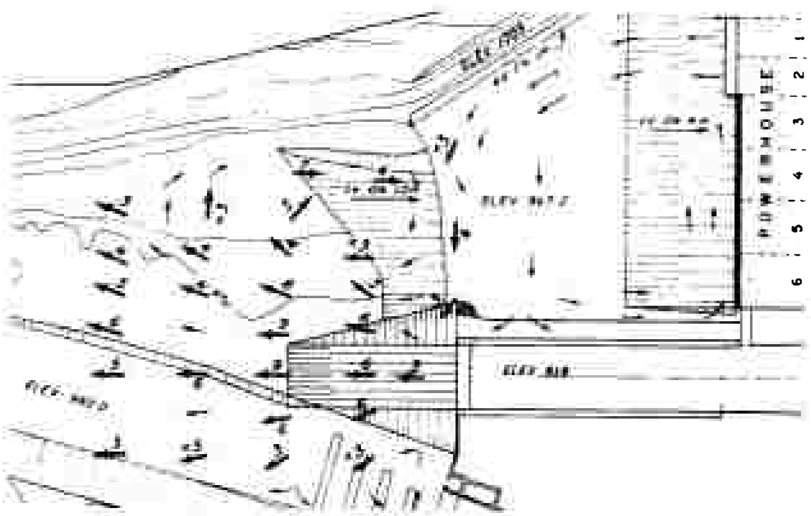
NOTES

1. DETAILS OF STILLING BASIN PLANS A TO A–3 ARE SHOWN ON PLATE 58.
2. TAILWATER FOR NATURAL RIVER CHANNEL AT GAGE 15 (PLATES 4 AND 5).
3. FOREBAY ELEVATION 1600.

MINIMUM TAILWATER FOR
ENERGY DISSIPATION
STILLING BASIN PLANS A TO A-3







NOTES

1 DETAILS OF STILLING BASINS ARE SHOWN ON PLATE 58
2 VELOCITIES WERE MEASURED IN FPS 3 FT ABOVE BOTTOM

OPERATING CONDITIONS

POWERHOUSE UNITS 1 AND 2 ... 5 000 CFS
SPILLWAY .... 40 000 CFS
TAILWATER ELEVATION 985.6

VELOCITIES
STILLING BASIN PLANS A-1 TO A-3
PLAN A SPILLWAY
RIVER DISCHARGE 45 000 CFS

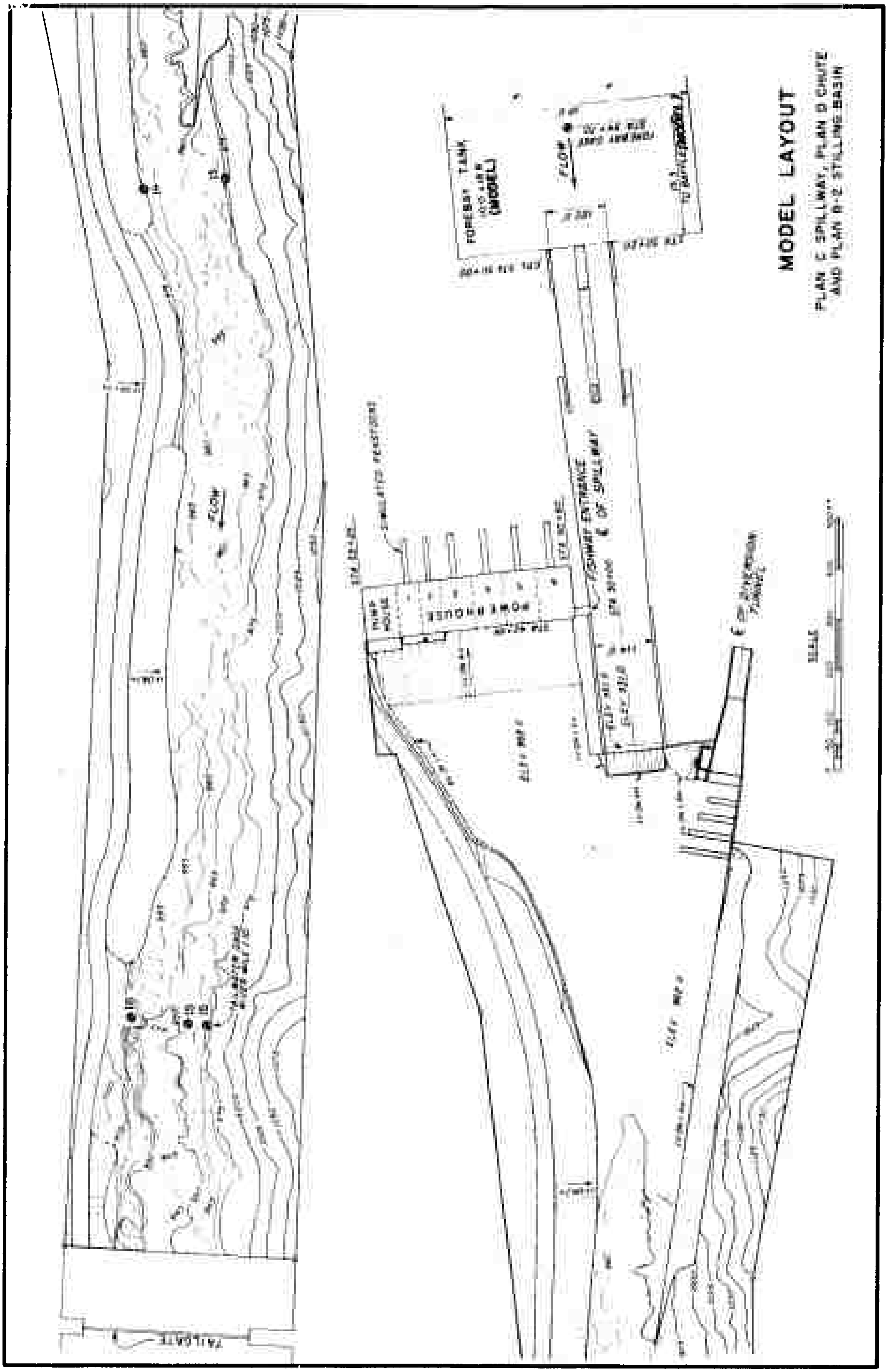

MODEL LAYOUT
PLAN C SPILLWAY, PLAN D CHUTE
AND PLAN B-2 STILLING BASIN
FOREBAY TANK
FLOW
FLOW
POWERHOUSE
PUMP HOUSE
FISHWAY ENTRANCE
℄ OF SPILLWAY
℄ OF DIVERSION TUNNEL
SCALE
TAILGATE

PLATE 61

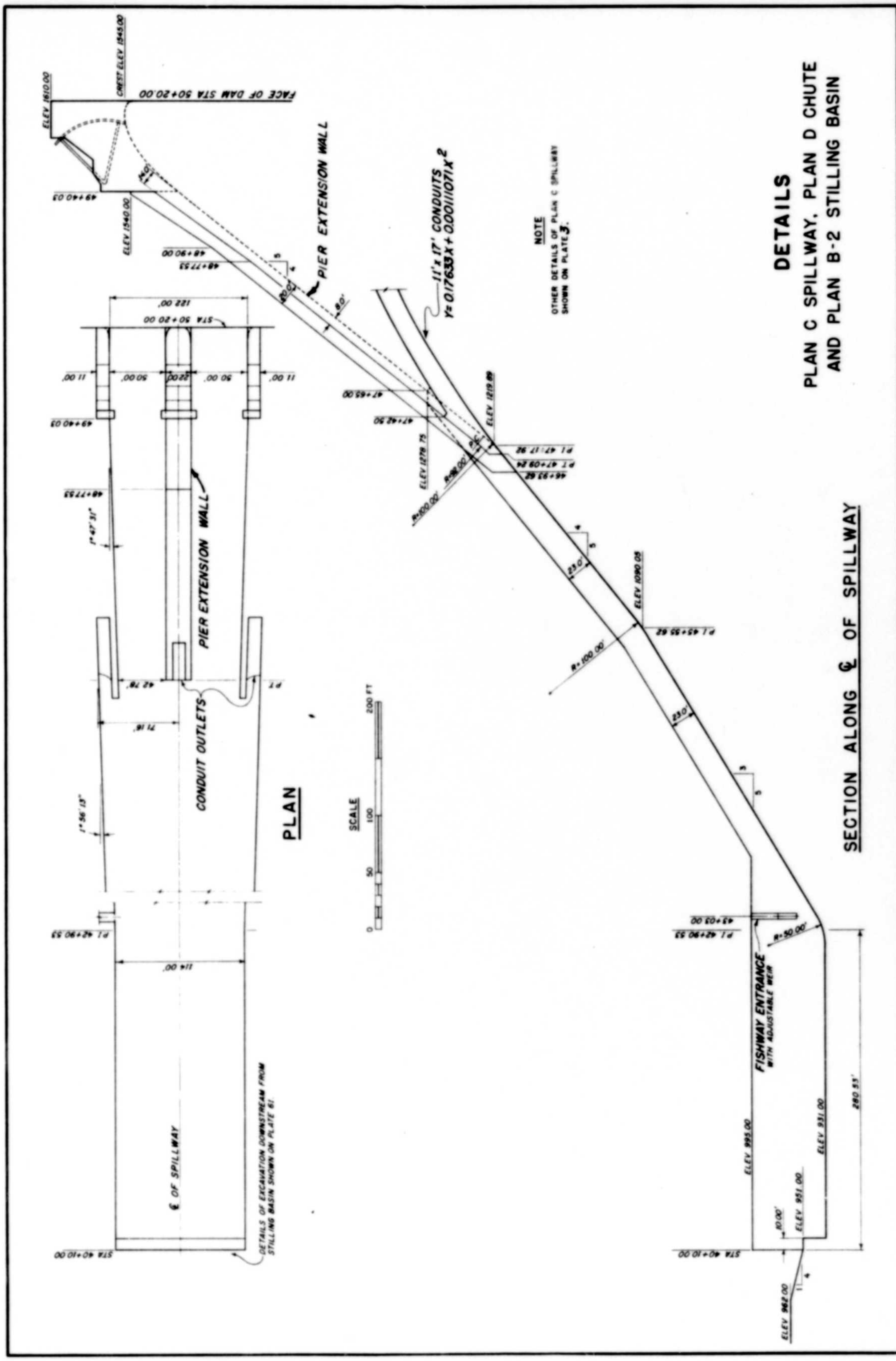
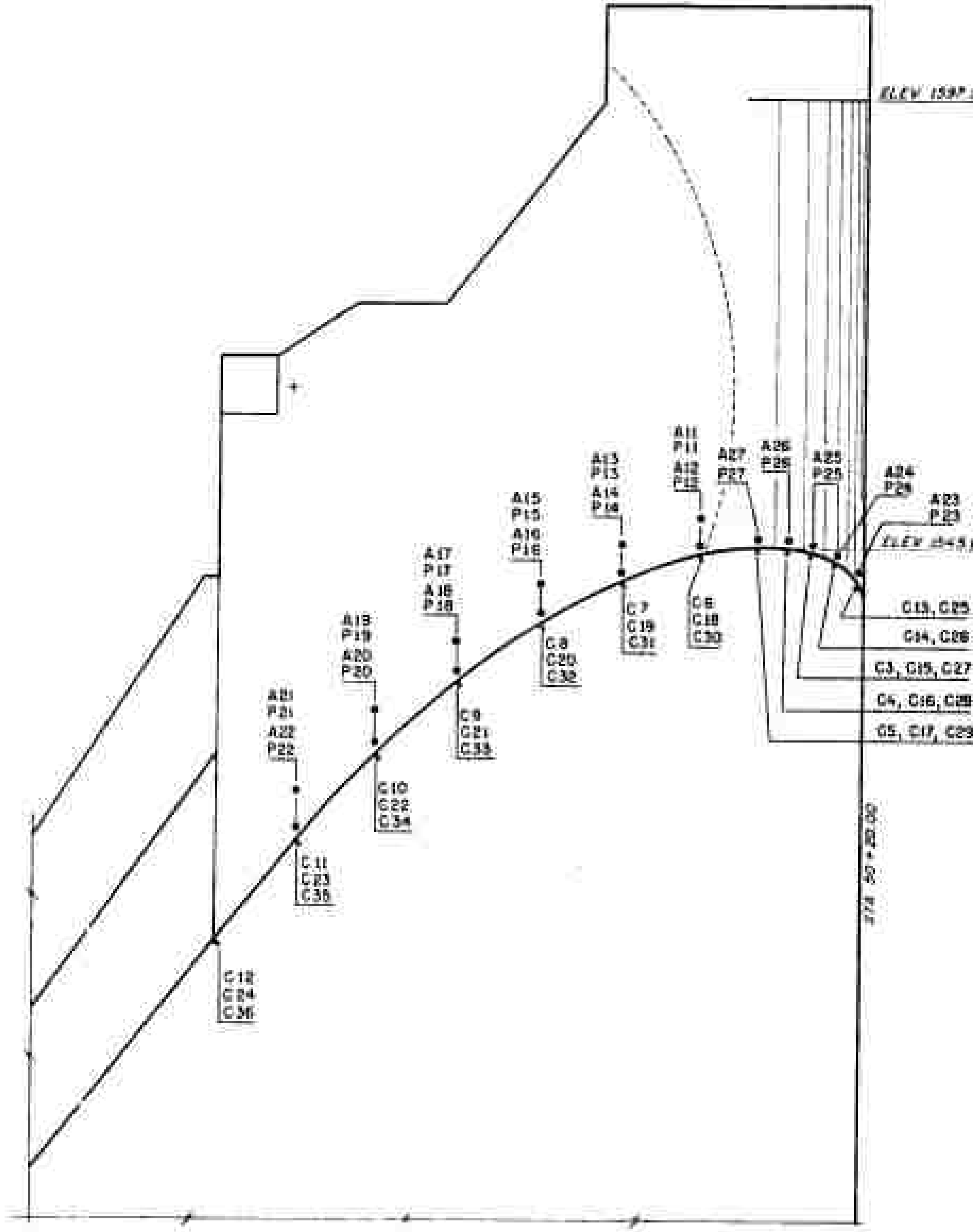
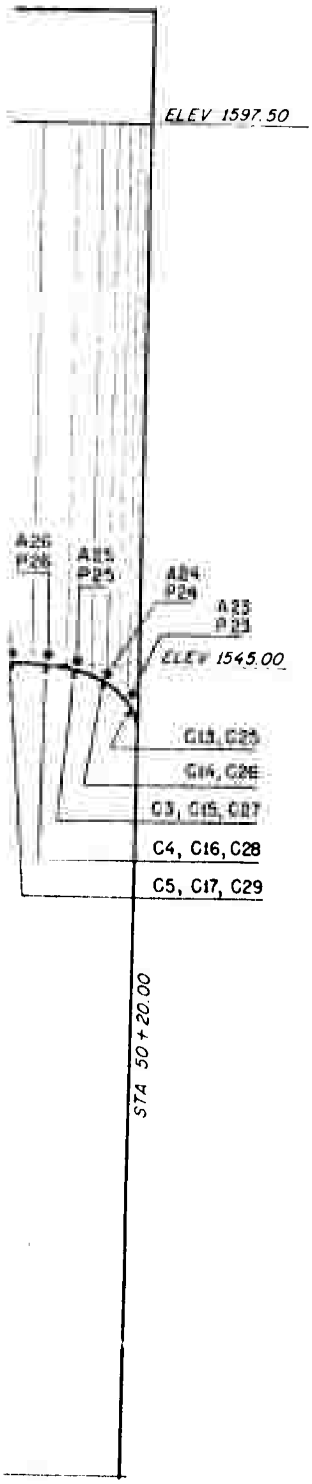

DETAILS
PLAN C SPILLWAY, PLAN D CHUTE
AND PLAN B-2 STILLING BASIN
FACE OF DAM STA 50+20.00
CREST ELEV 1545.00
ELEV 1610.00
49+40.03
ELEV 1540.00
PIER EXTENSION WALL
11'x17' CONDUITS
Y=0.17633X+0.0011071X²
NOTE
OTHER DETAILS OF PLAN C SPILLWAY SHOWN ON PLATE 3.
48+90.00
48+77.53
122.00'
STA 50+20.00
47+65.00
47+42.50
ELEV 1219.89
PI 47+17.26
PT 47+09.24
46+93.62
ELEV 1278.75
R=100.00'
23.0'
ELEV 1090.05
PI 45+55.62
PIER EXTENSION WALL
CONDUIT OUTLETS
PLAN
SCALE
SECTION ALONG ℄ OF SPILLWAY
FISHWAY ENTRANCE
WITH ADJUSTABLE WEIR
PI 42+90.53
43+03.00
R=50.00'
114.00'
ELEV 995.00
ELEV 931.00
280.53'
ELEV 951.00
10.00'
STA 40+10.00
ELEV 962.00
℄ OF SPILLWAY
DETAILS OF EXCAVATION DOWNSTREAM FROM STILLING BASIN SHOWN ON PLATE 61.

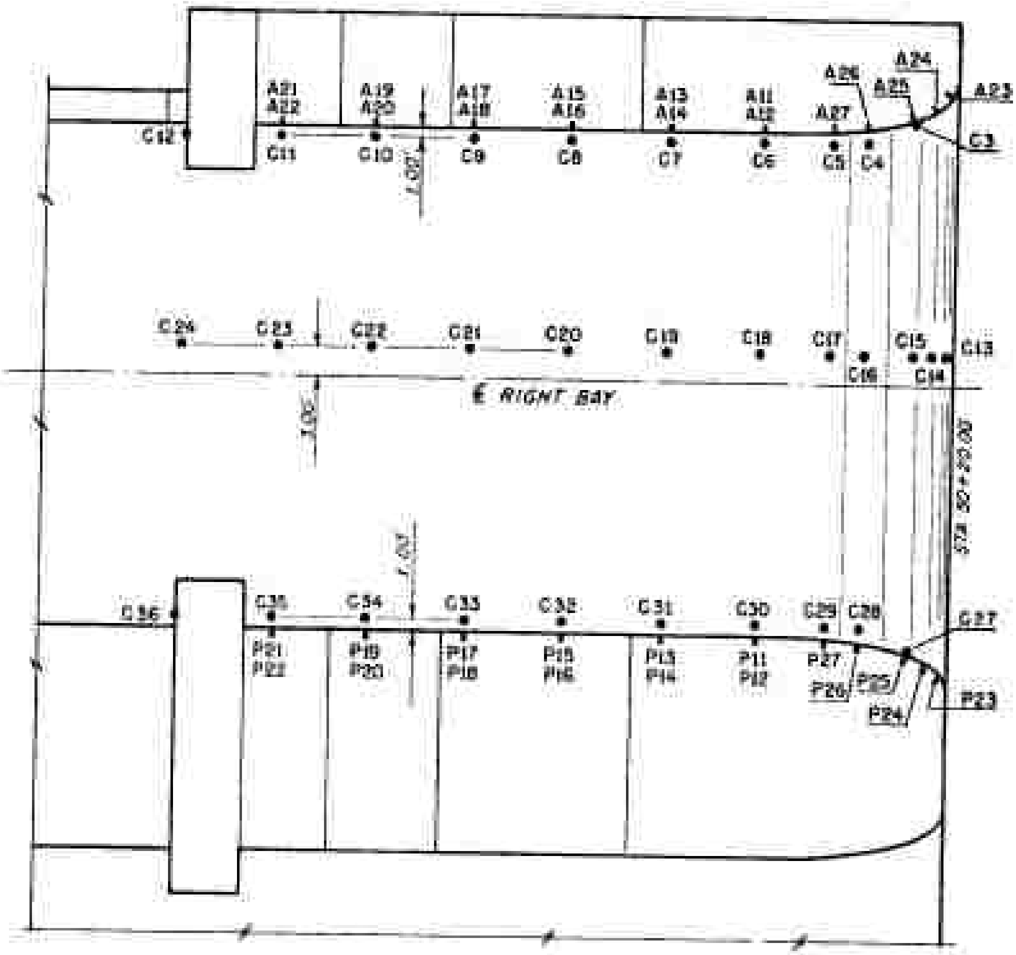
PLATE 62



ELEVATION

Plate 63

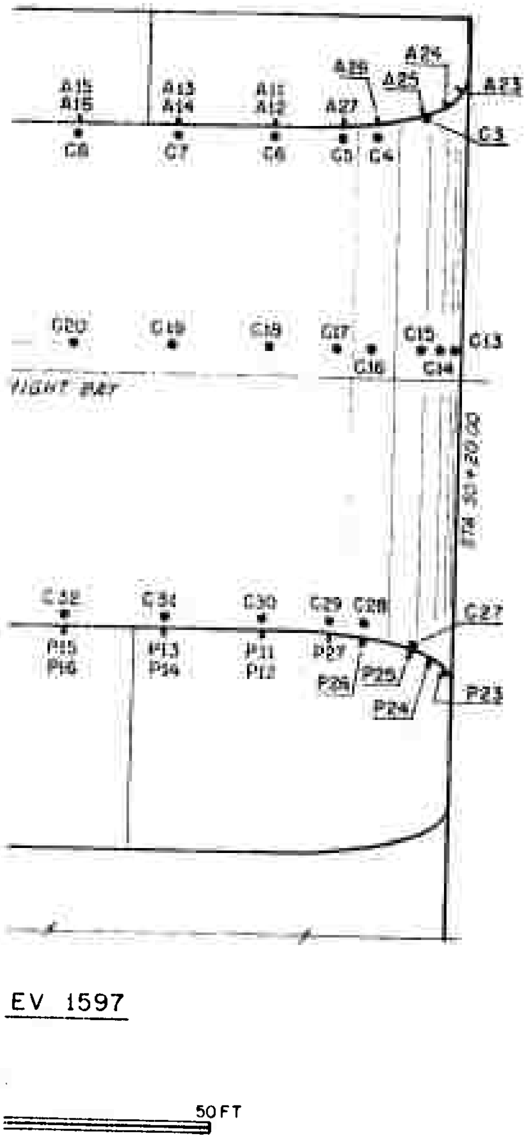




PLAN AT ELEV 1597

SCALE

0 5 10 15 20 25 50 FT



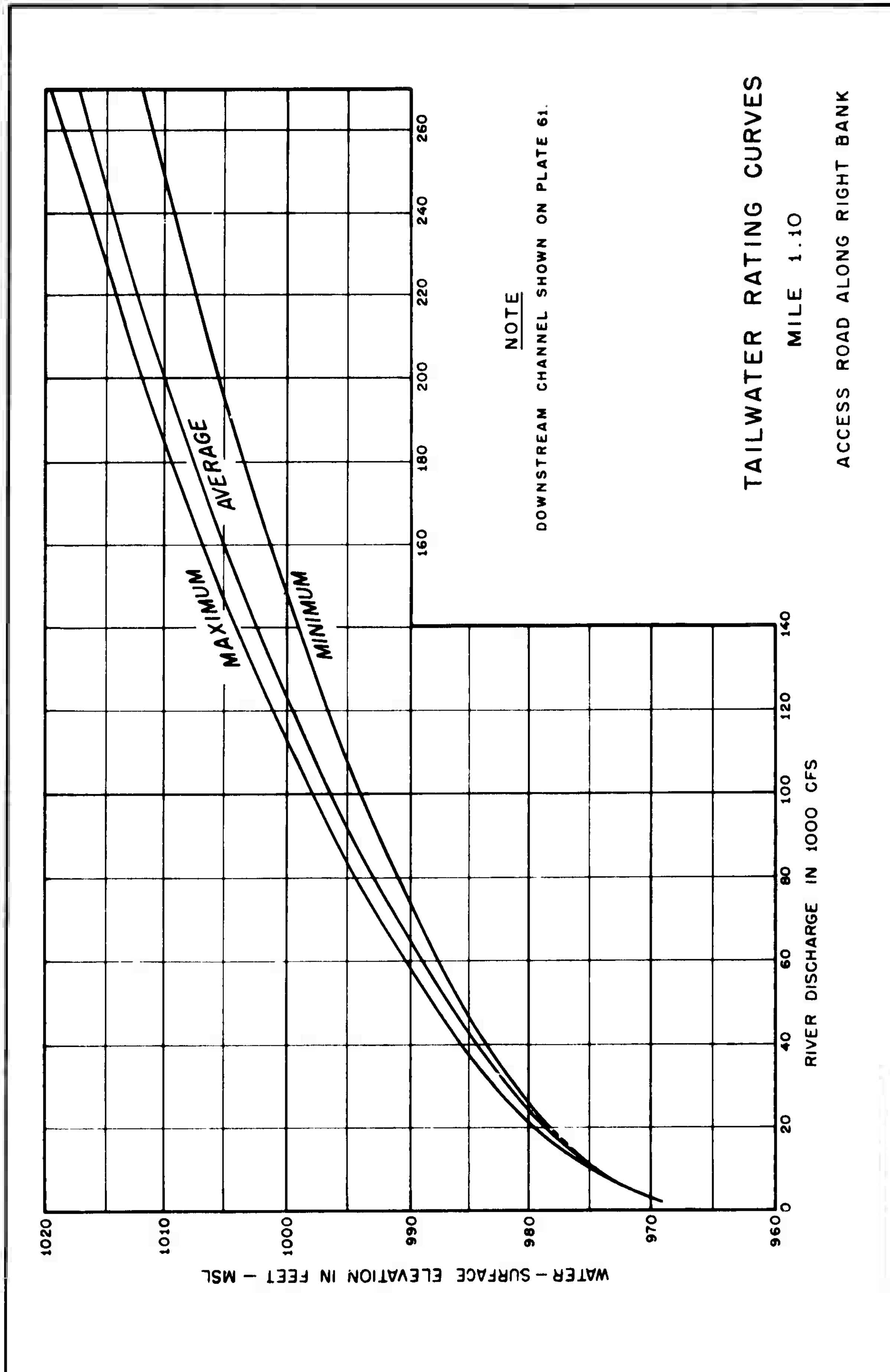
PIEZOMETER LOCATIONS		
PIEZO NO.	STATION	ELEVATION
C13,	50+19.50	1540.43
C14,	50+17.00	1542.64
C3, C15, C27	50+14.00	1544.02
C4, C16, C28	50+11.00	1544.75
C5, C17, C29	50+07.73	1545.00
C6, C18, C30	50+00.00	1544.14
C7, C19, C31	49+90.00	1541.02
C8, C20, C32	49+80.00	1535.88
C9, C21, C33	49+70.00	1528.89
C10, C22, C34	49+60.00	1520.10
C11, C23, C35	49+50.00	1509.60
C12, C24, C36	49+40.00	1497.43
A23, P23	50+19.50	1541.43
A24, P24	50+17.00	1543.64
A25, P25	50+14.00	1545.02
A26, P26	50+11.00	1545.75
A27, P27	50+07.73	1546.00
A11, P11	50+00.00	1548.14
A12, P12	50+00.00	1545.14
A13, P13	49+90.00	1545.02
A14, P14	49+90.00	1542.02
A15, P15	49+80.00	1539.88
A16, P16	49+80.00	1536.88
A17, P17	49+70.00	1532.89
A18, P18	49+70.00	1529.89
A19, P19	49+60.00	1524.10
A20, P20	49+60.00	1521.10
A21, P21	49+50.00	1513.60
A22, P22	49+50.00	1510.60

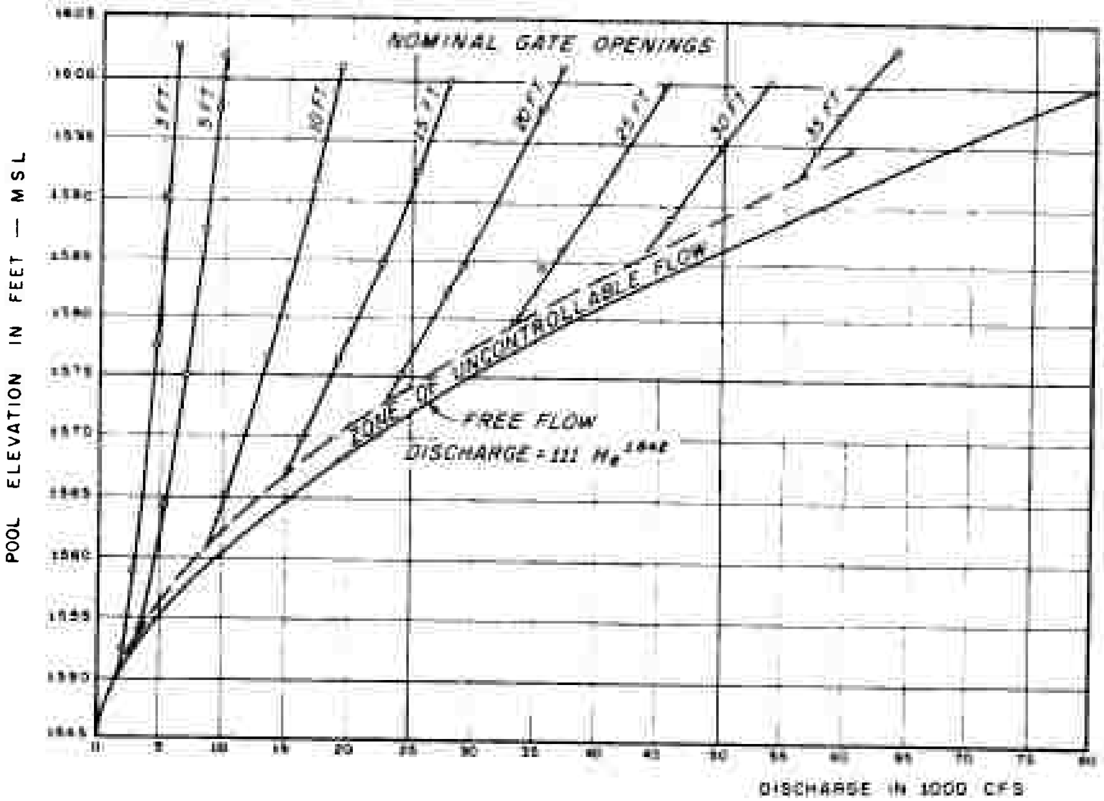
PIEZOMETER LOCATIONS

CREST, PIER, AND ABUTMENTS

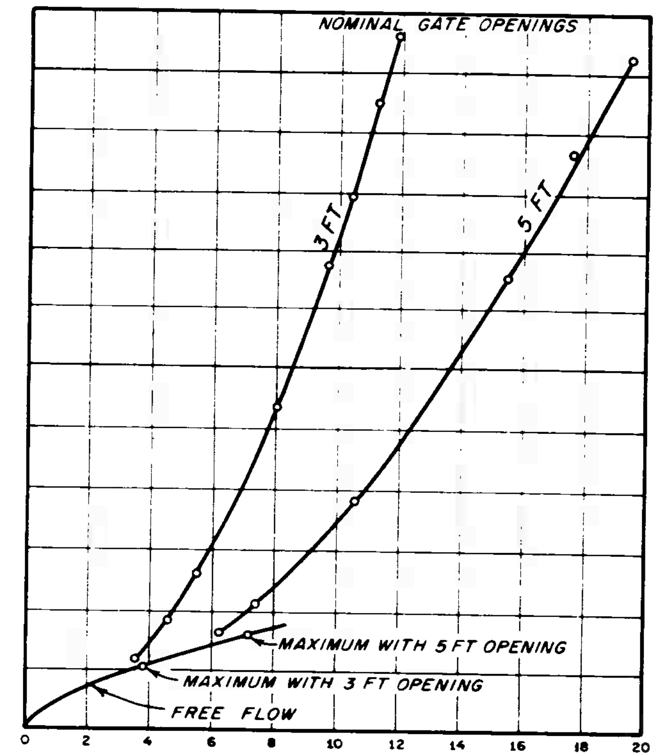
PLAN C SPILLWAY

3 of 3


TAILWATER RATING CURVES
MILE 1.10
ACCESS ROAD ALONG RIGHT BANK
NOTE
DOWNSTREAM CHANNEL SHOWN ON PLATE 61.
MAXIMUM
AVERAGE
MINIMUM
RIVER DISCHARGE IN 1000 CFS
WATER – SURFACE ELEVATION IN FEET – MSL
0
20
40
60
80
100
120
140
160
180
200
220
240
260
960
970
980
990
1000
1010
1020



SINGLE BAY OPERATION



TWO BAY OPERATION

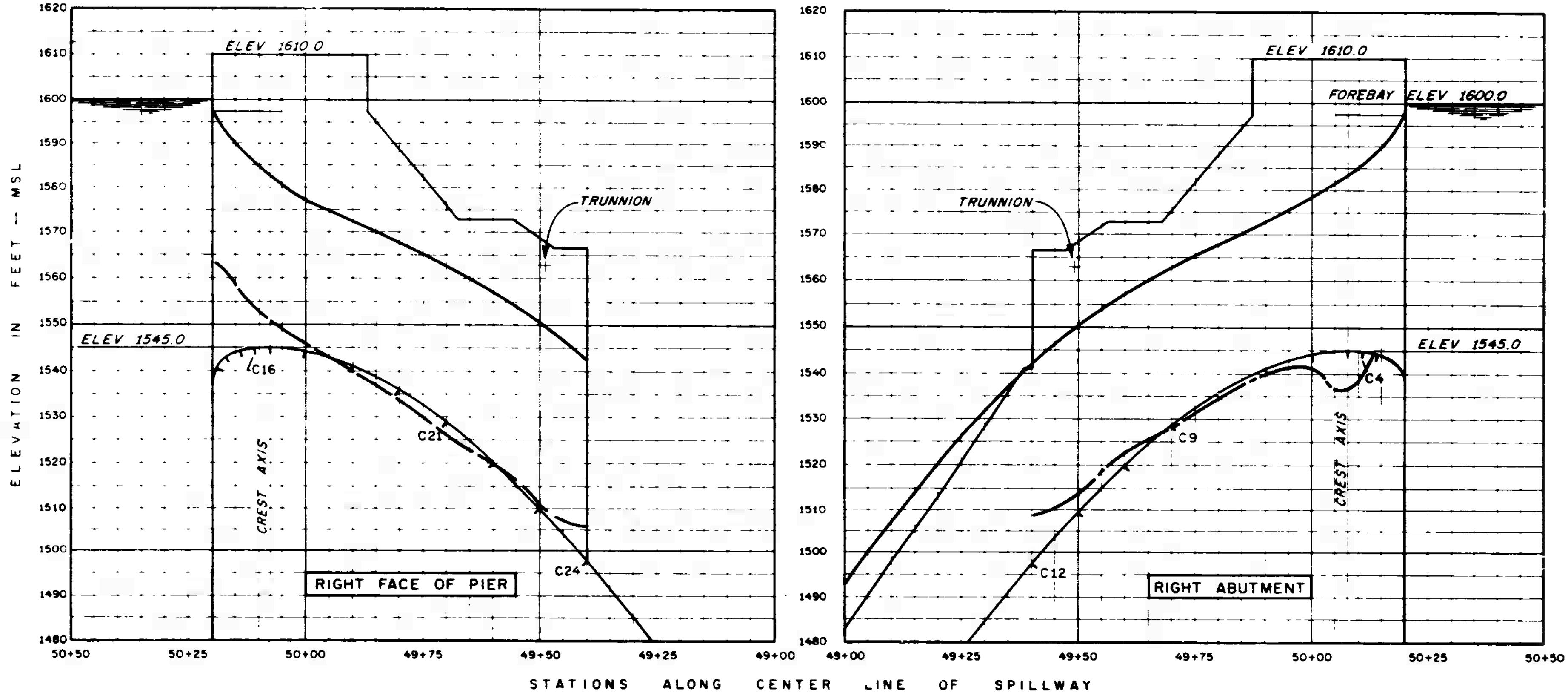
NOTE

DETAILS OF PLAN C SPILLWAY
ARE SHOWN ON PLATE 62.

DISCHARGE RATING CURVE

PLAN C SPILLWAY

GATED FLOW

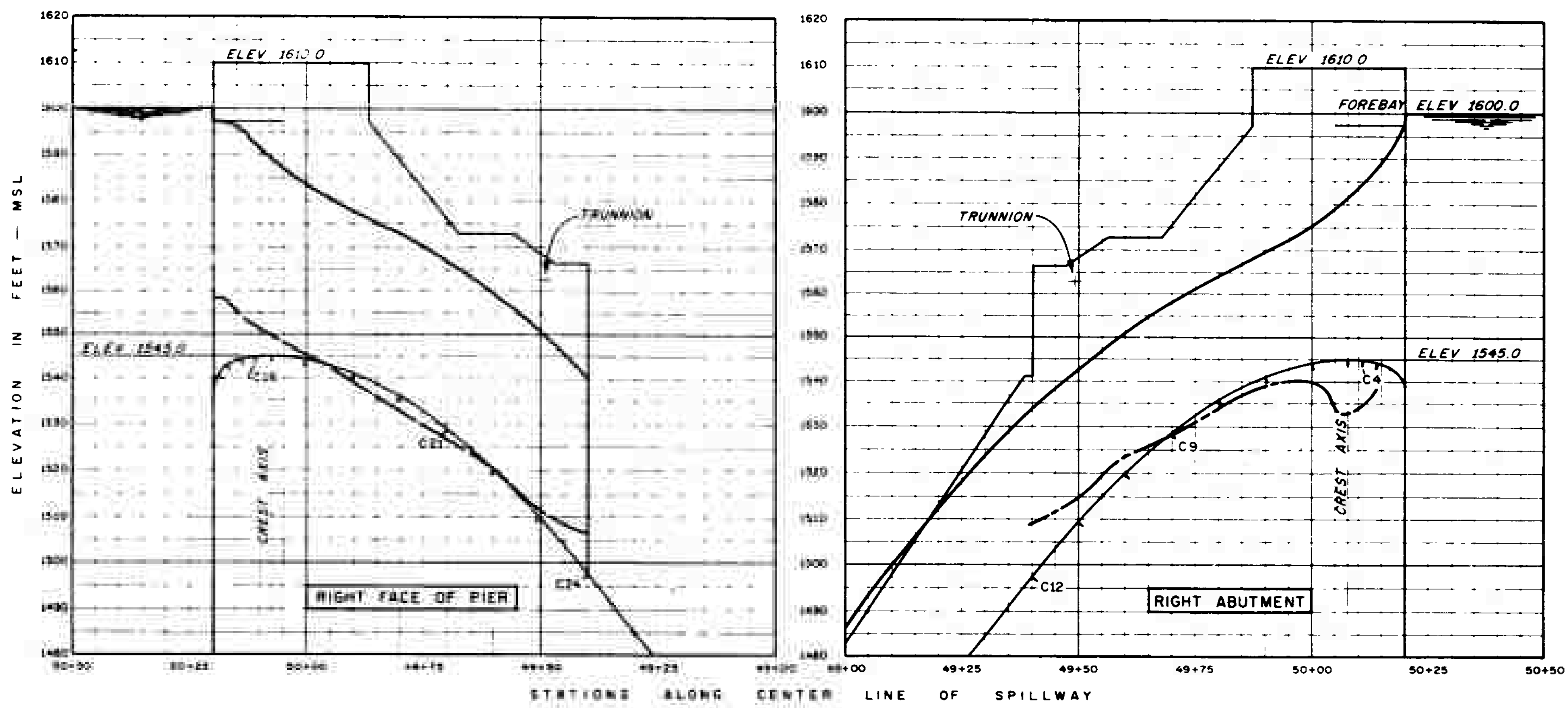


LEGEND

- WATER-SURFACE PROFILE ALONG RIGHT ABUTMENT OR PIER
- PRESSURE PROFILE AT CENTER LINE OF RIGHT BAY
- PRESSURE PROFILE ON CREST NEAR RIGHT ABUTMENT

ONE - BAY OPERATION
FREE FLOW

WATER - SURFACE
AND PRESSURE PROFILES
PLAN C SPILLWAY STRUCTURES
SPILLWAY DISCHARGE 80 000 CFS



LEGEND

- WATER-SURFACE PROFILE ALONG RIGHT ABUTMENT OR PIER
- PRESSURE PROFILE AT CENTER LINE OF RIGHT BAY
- PRESSURE PROFILE ON CREST NEAR RIGHT ABUTMENT

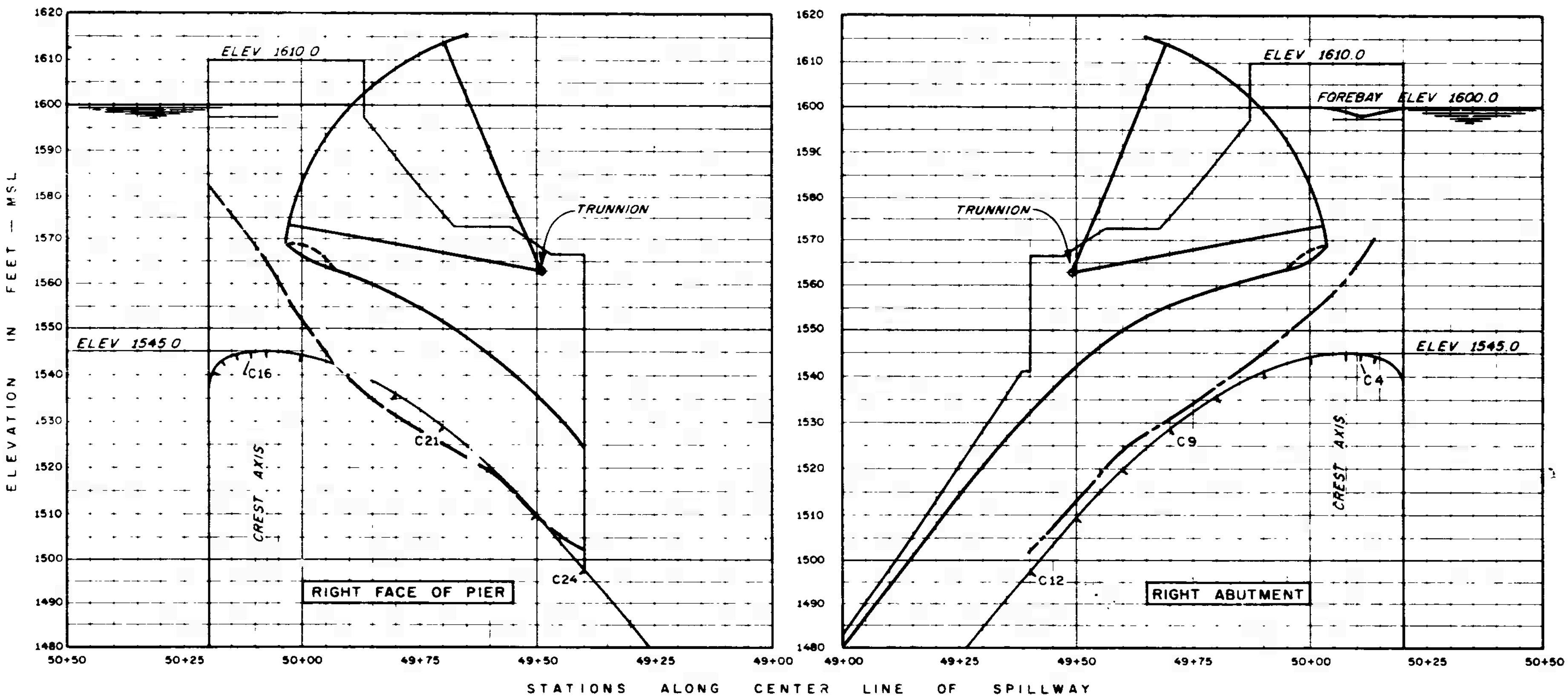
TWO-BAY OPERATION

FREE FLOW

WATER-SURFACE AND PRESSURE PROFILES

PLAN C SPILLWAY STRUCTURES

SPILLWAY DISCHARGE 157 200 CFS



LEGEND

- WATER-SURFACE PROFILE ALONG RIGHT ABUTMENT OR PIER
- PRESSURE PROFILE AT CENTER LINE OF RIGHT BAY
- PRESSURE PROFILE ON CREST NEAR RIGHT ABUTMENT
- RIDEUP ALONG RIGHT ABUTMENT OR PIER

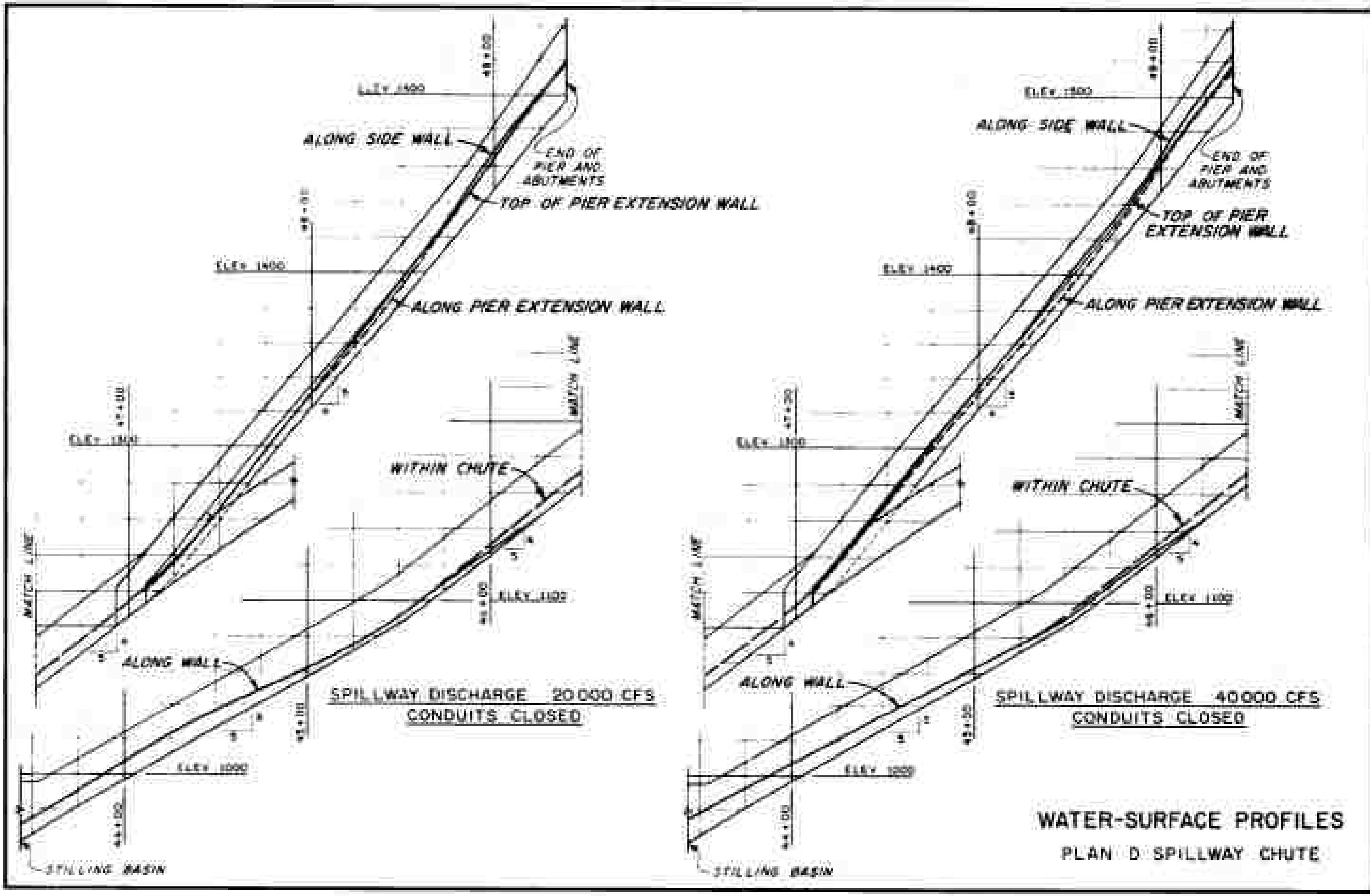
TWO-BAY OPERATION

GATED FLOW

WATER-SURFACE AND PRESSURE PROFILES

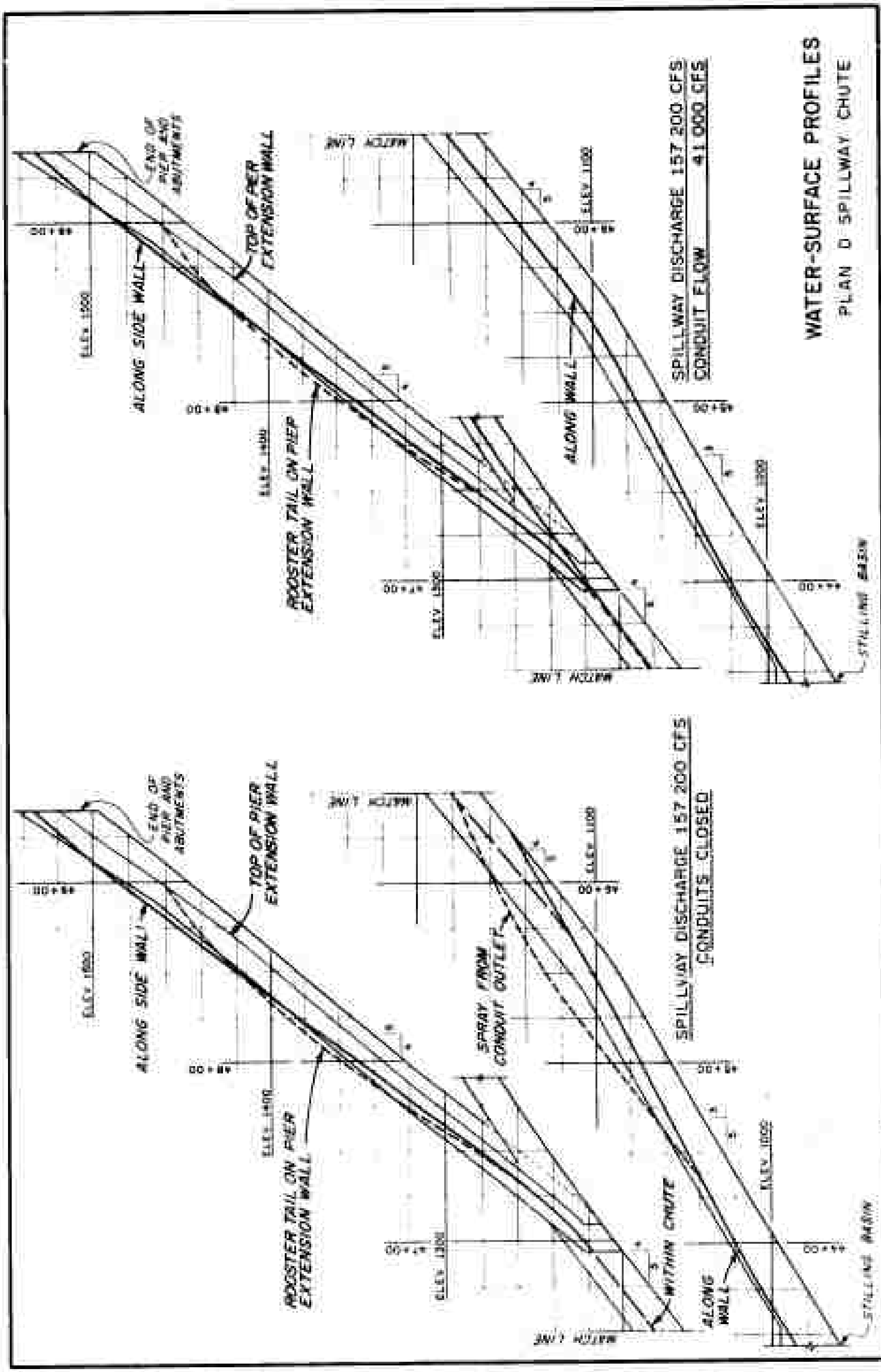
PLAN C SPILLWAY STRUCTURES

SPILLWAY DISCHARGE 90 000 CFS



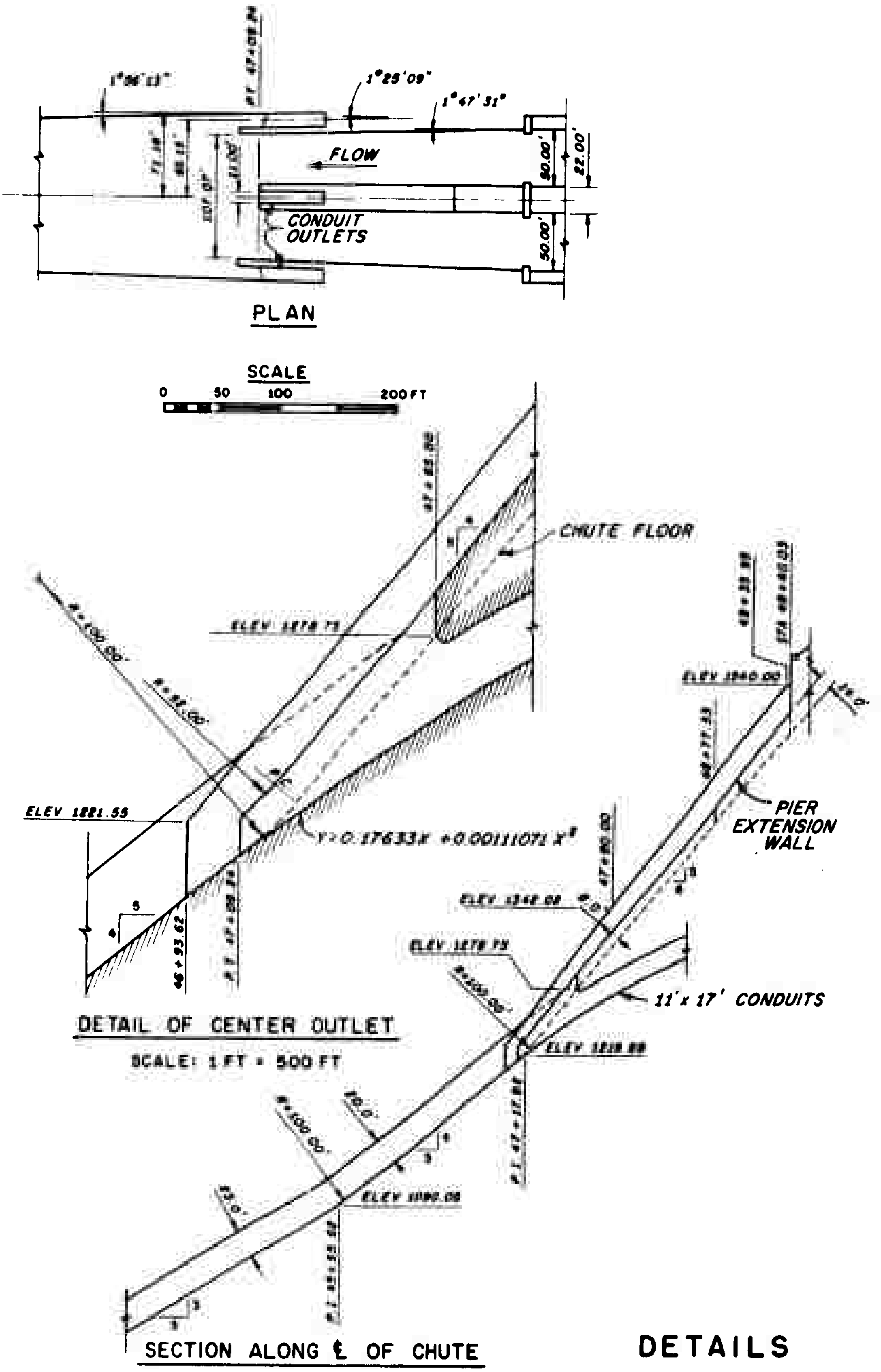
WATER-SURFACE PROFILES
PLAN D SPILLWAY CHUTE

PLATE 69



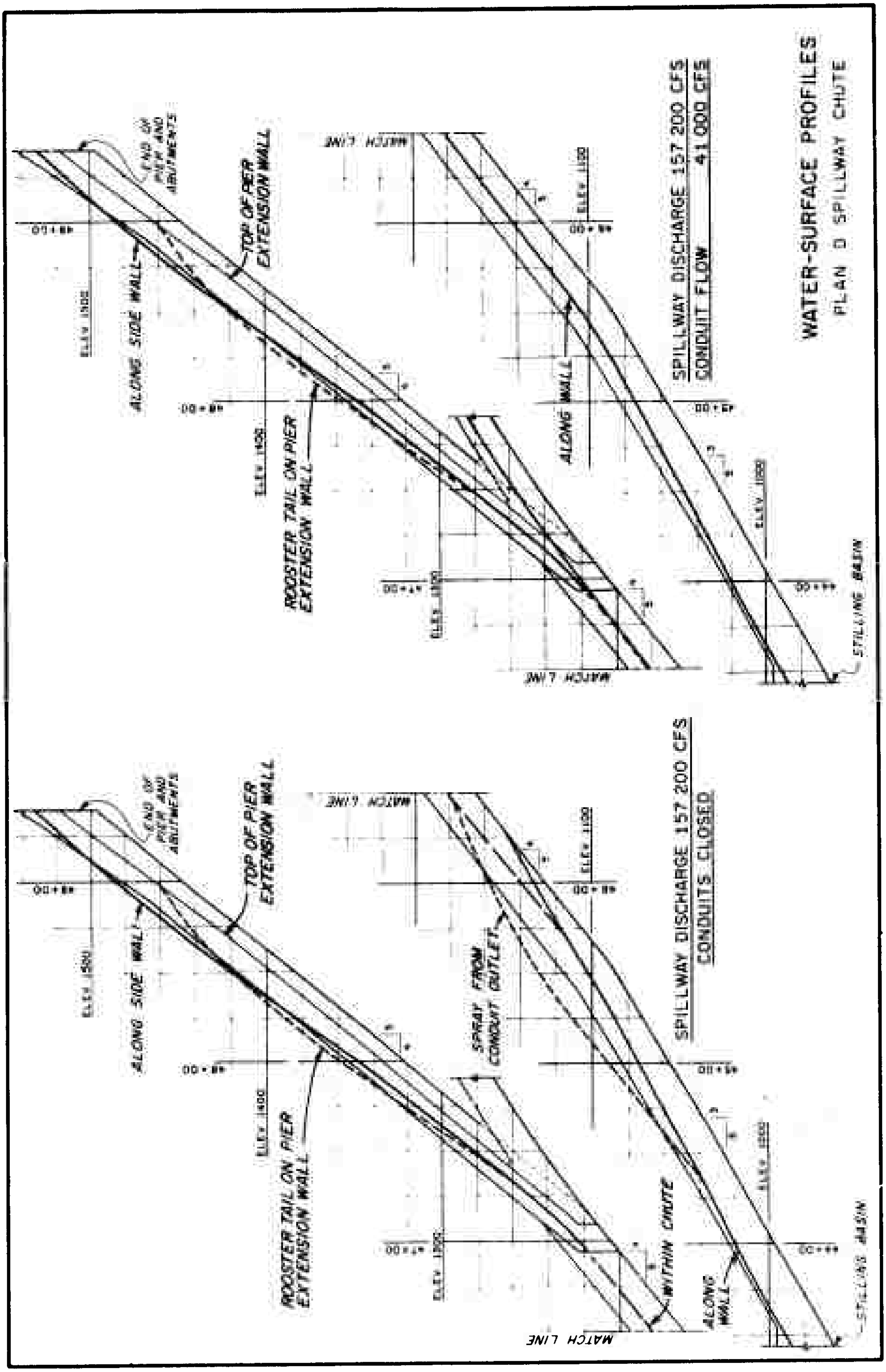
WATER-SURFACE PROFILES
PLAN D SPILLWAY CHUTE
SPILLWAY DISCHARGE 157 200 CFS
CONDUIT FLOW 41 000 CFS
SPILLWAY DISCHARGE 157 200 CFS
CONDUITS CLOSED
END OF PIER AND ABUTMENTS
TOP OF PIER EXTENSION WALL
ALONG SIDE WALL
ROOSTER TAIL ON PIER EXTENSION WALL
ALONG WALL
SPRAY FROM CONDUIT OUTLET
WITHIN CHUTE
MATCH LINE
STILLING BASIN
ELEV 1500
ELEV 1400
ELEV 1300
ELEV 1200
ELEV 1100

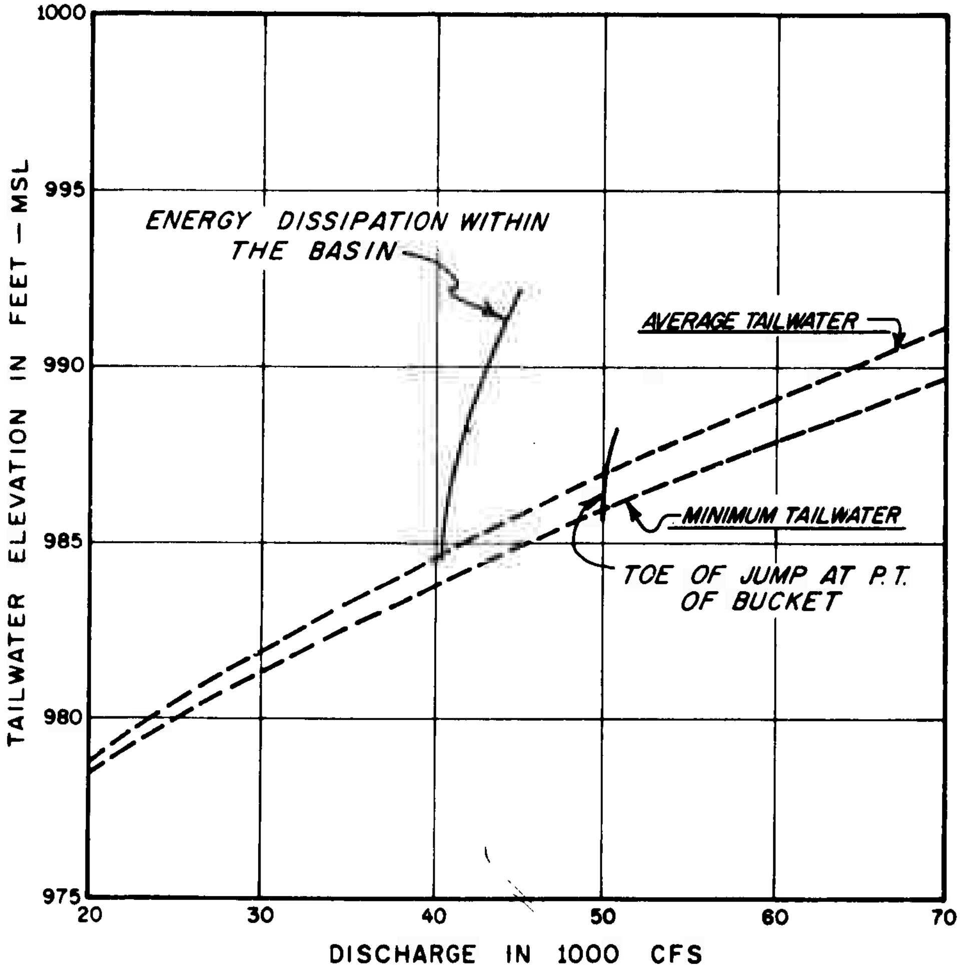
PLATE 70



DETAILS

PLAN D-1 CHUTE

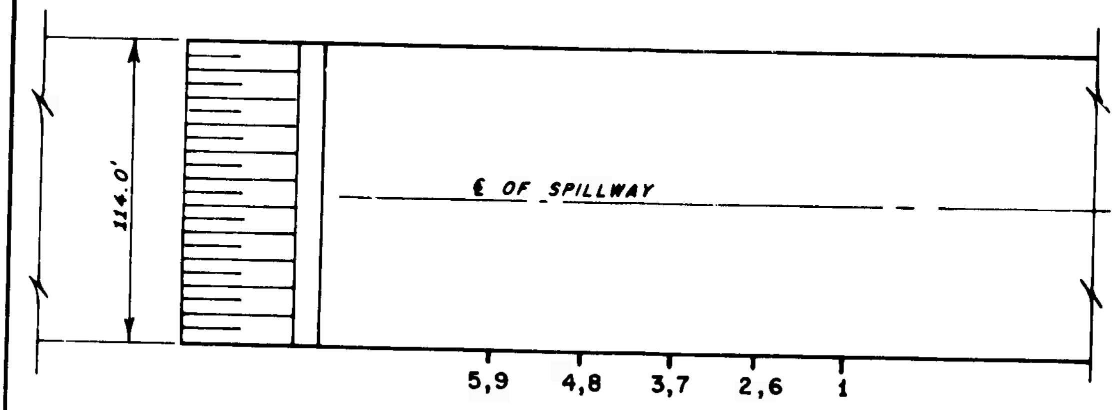

WATER-SURFACE PROFILES
PLAN D SPILLWAY CHUTE
SPILLWAY DISCHARGE 157 200 CFS
CONDUIT FLOW 41 000 CFS
ALONG SIDE WALL
TOP OF PIER EXTENSION WALL
END OF PIER AND ABUTMENTS
ROOSTER TAIL ON PIER EXTENSION WALL
MATCH LINE
ALONG WALL
STILLING BASIN
SPILLWAY DISCHARGE 157 200 CFS
CONDUITS CLOSED
SPRAY FROM CONDUIT OUTLET
WITHIN CHUTE



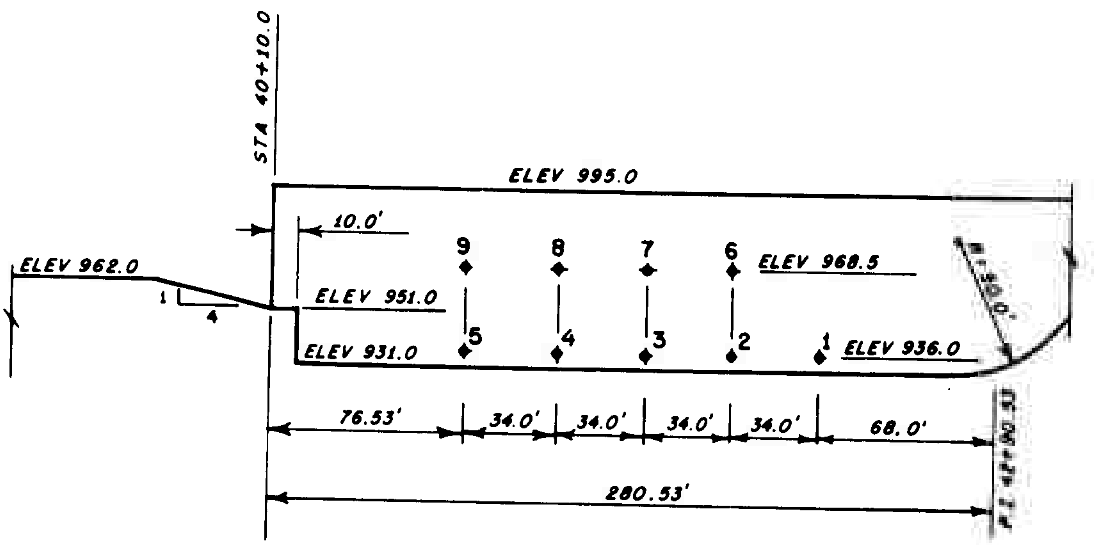
NOTES

1. DETAILS OF STILLING BASIN SHOWN ON PLATE 62.
2. DETAILS OF DOWNSTREAM CHANNEL AND LOCATION OF TAILWATER GAGE SHOWN ON PLATE 61.
3. FOREBAY ELEVATION 1600.

MINIMUM TAILWATER
FOR ENERGY DISSIPATION
PLAN B-2 STILLING BASIN



PLAN



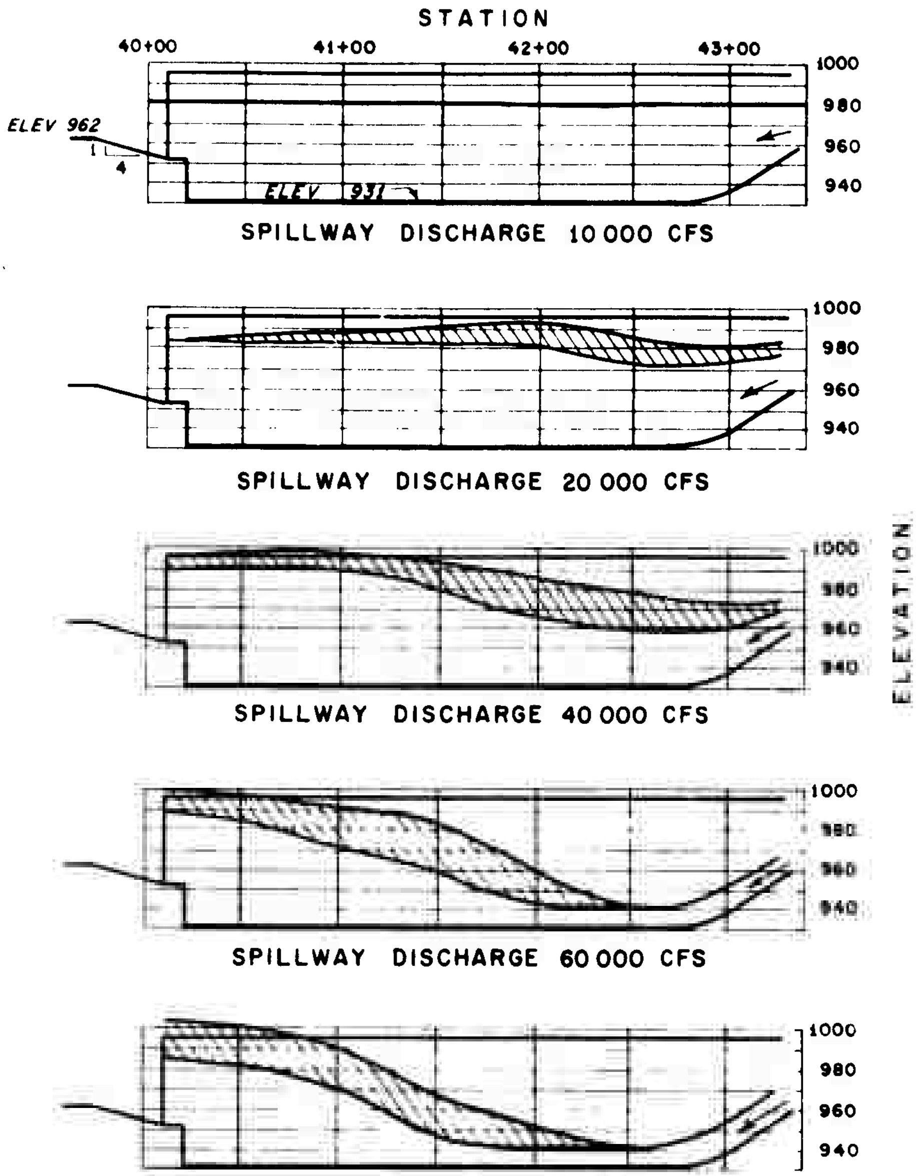
ELEVATION

NOTE

PRESSURE CELL 1 NOT USED

PRESSURE CELL LOCATIONS

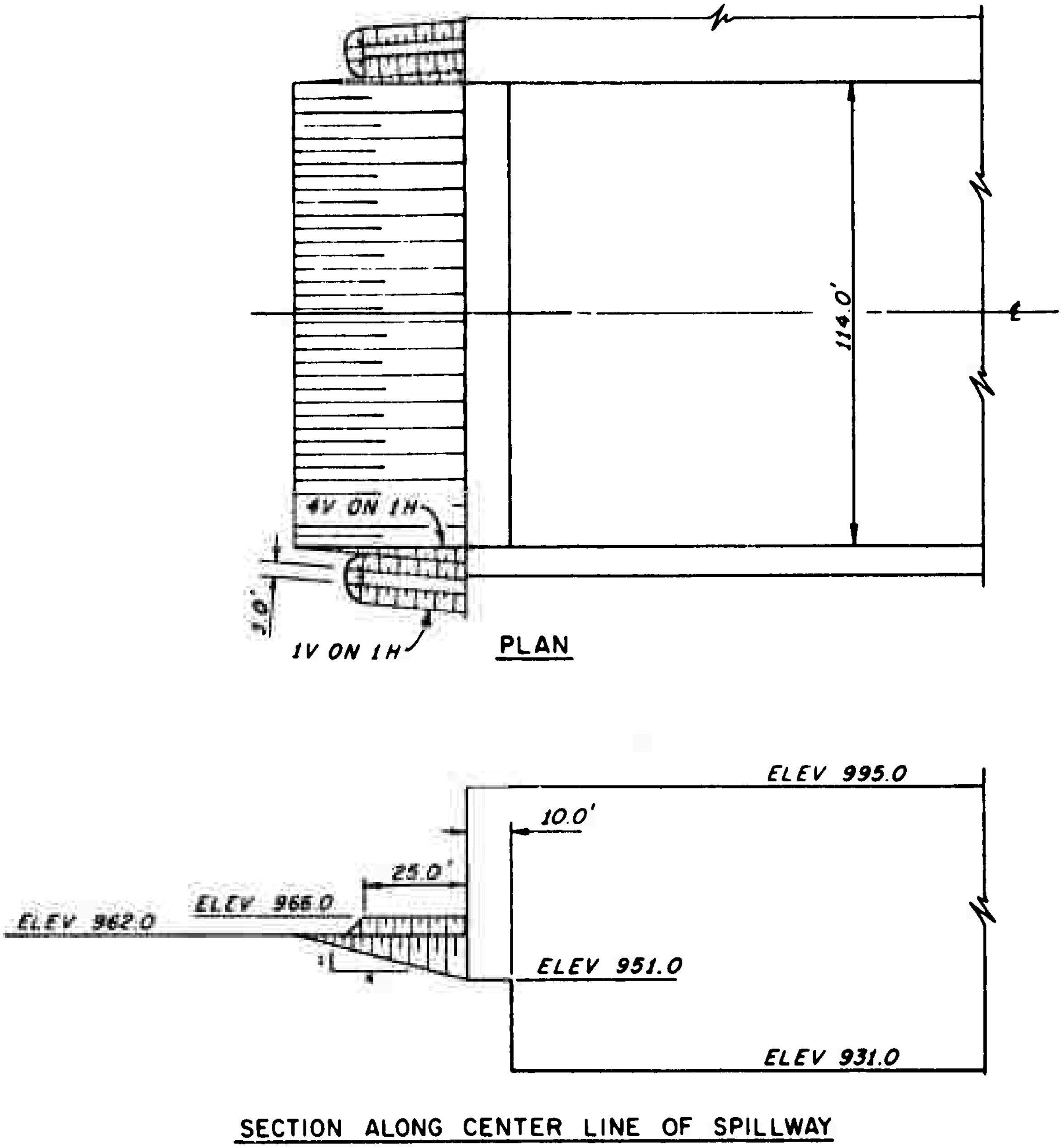
PLAN B-2 STILLING BASIN



NOTES

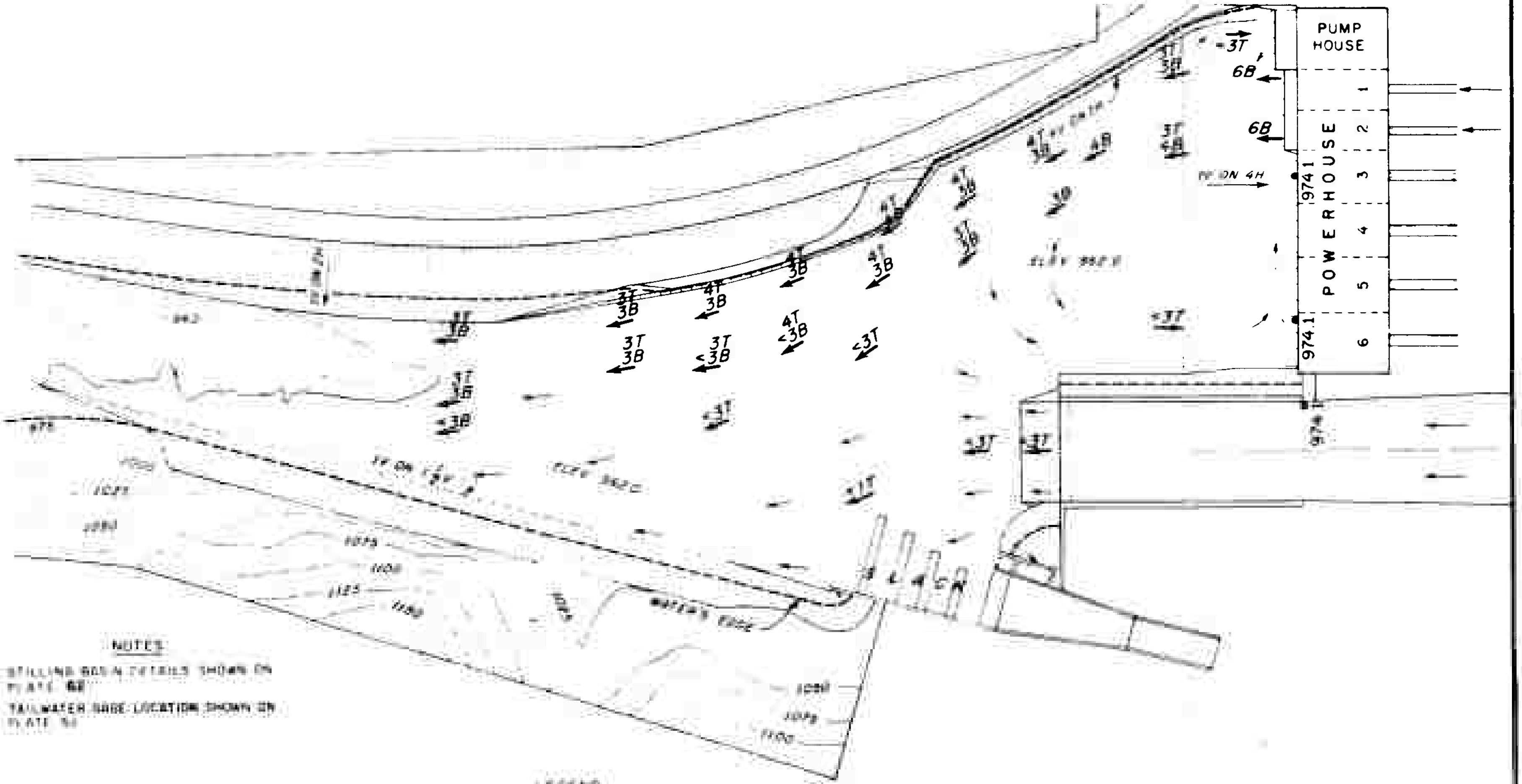
1. RIVER FLOW EQUALS SPILLWAY DISCHARGE PLUS 5000 CFS POWER-HOUSE DISCHARGE.
2. NORMAL RANGE OF WATER-SURFACE VARIATIONS SHOWN.
3. STILLING BASIN DETAILS SHOWN ON PLATE 62.

WATER-SURFACE PROFILES
PLAN B-2 STILLING BASIN
AVERAGE TAILWATERS



DETAILS

STILLING BASIN
WALL EXTENSION FILLS



NOTES

1. STILLING BASIN DETAILS SHOWN ON PLATE 62
2. TAILWATER GAGE LOCATION SHOWN ON PLATE 51

OPERATING CONDITIONS

POWERHOUSE UNITS 1 AND 2 5000 CFS
SPILLWAY 2000 CFS
TAILWATER ELEVATION STA 6 AT GAGE 15

LEGEND

VELOCITIES MEASURED IN FPS
T 3 FT DEPTH
B 3 FT ABOVE BOTTOM
974.1 ● WATER SURFACE ELEVATION

SCALE

0 50 100 150 200 250 FT

FLOW CONDITIONS

PLAN B DOWNSTREAM CHANNEL

PLAN B-2 STILLING BASIN

RIVER DISCHARGE 7000 CFS

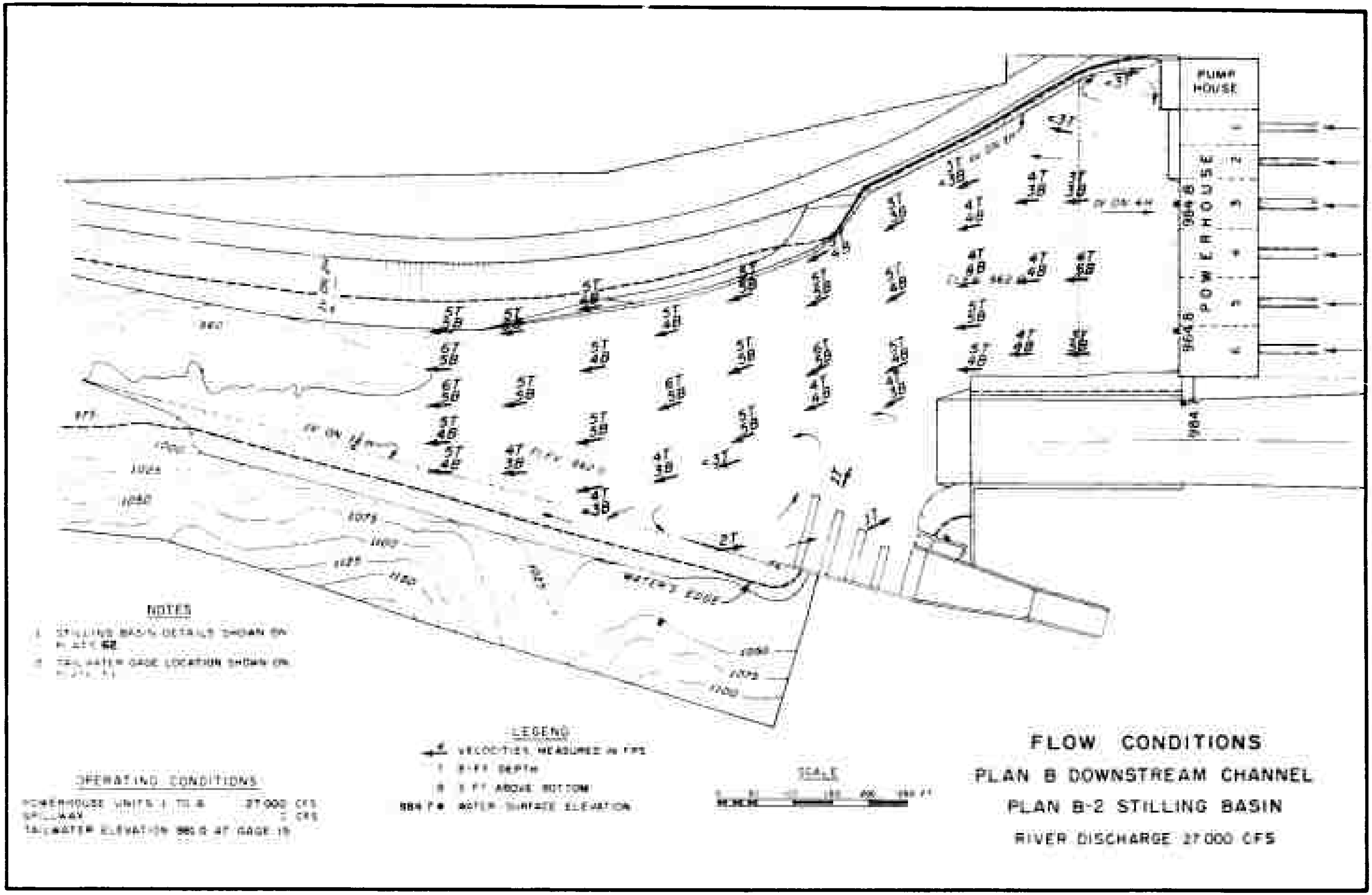
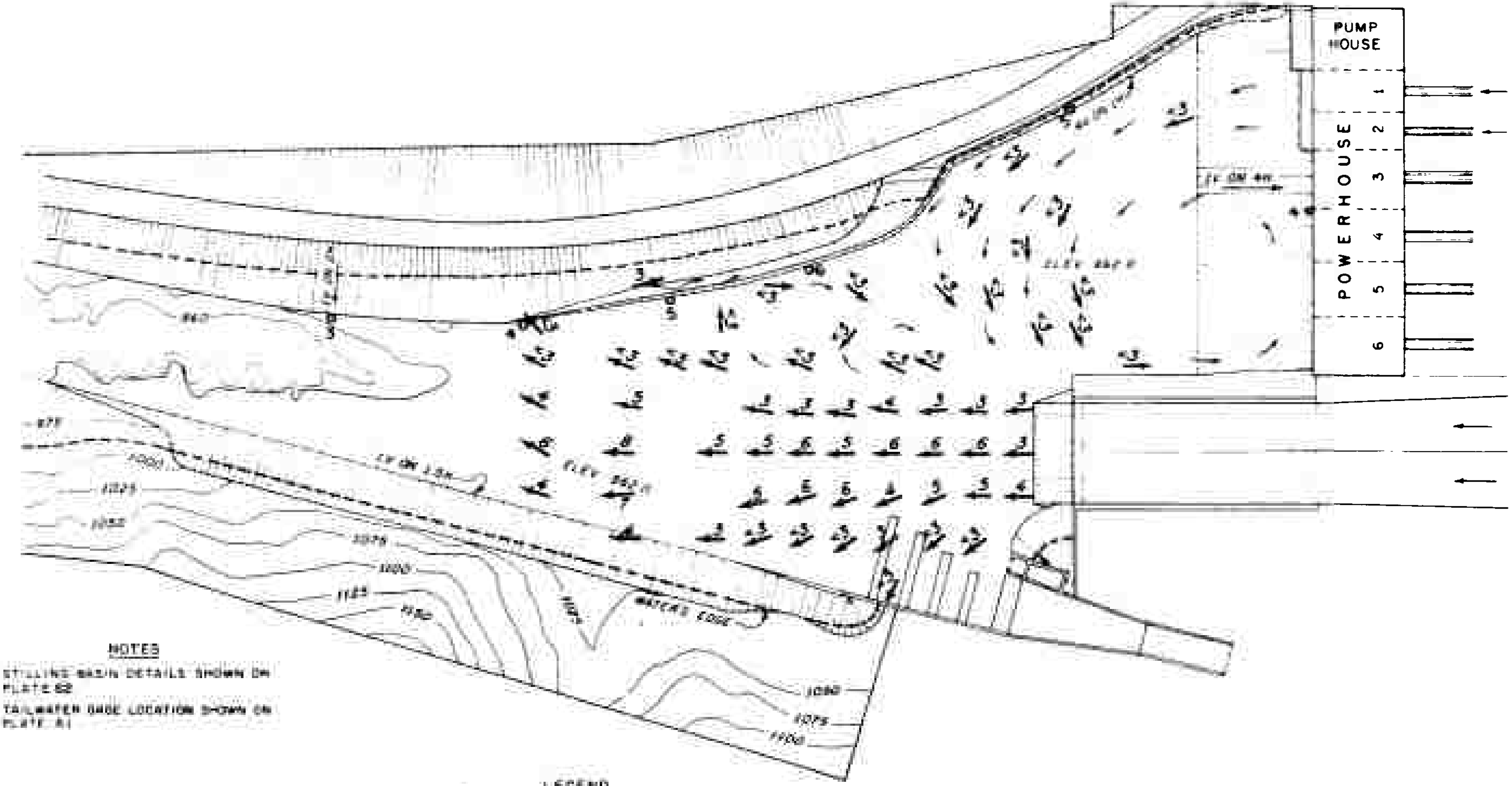

FLOW CONDITIONS
PLAN B DOWNSTREAM CHANNEL
PLAN B-2 STILLING BASIN
RIVER DISCHARGE 27 000 CFS
LEGEND
VELOCITIES MEASURED IN FPS
T 0.5 FT DEPTH
B 1 FT ABOVE BOTTOM
984.7 ● WATER SURFACE ELEVATION
SCALE
NOTES
OPERATING CONDITIONS
PUMP HOUSE
POWERHOUSE
WATER'S EDGE

PLATE 77



NOTES

1. STILLING BASIN DETAILS SHOWN ON PLATE 62
2. TAILWATER GAGE LOCATION SHOWN ON PLATE 81

OPERATING CONDITIONS

POWERHOUSE UNITS 1 AND 2 — 5,000 CFS
SPILLWAY — 40,000 CFS
TAILWATER ELEVATION 885.8 AT GAGE 15
AVERAGE W.S. ELEV 890.0 BETWEEN POWERHOUSE UNITS 3 AND 4

LEGEND

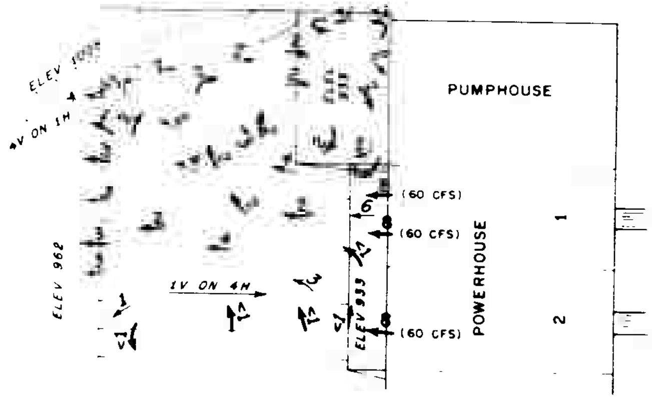
VELOCITIES MEASURED IN FPS 1 FT ABOVE BOTTOM

4.0 WAVE HEIGHTS IN FEET

SCALE

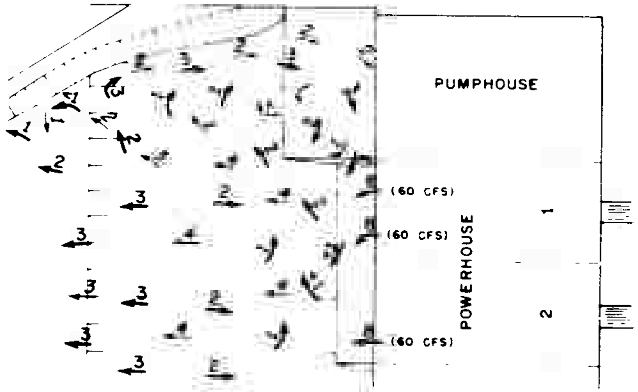
0 50 100 150 200 250 FT

FLOW CONDITIONS
PLAN B DOWNSTREAM CHANNEL
PLAN B-2 STILLING BASIN
RIVER DISCHARGE 45,000 CFS



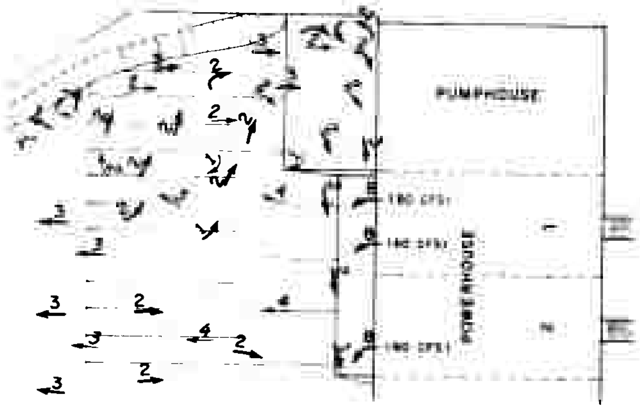
POWERHOUSE UNIT 1 OPERATING

POWERHOUSE DISCHARGE 2 500 CFS
PUMPHOUSE INFLOW 550 CFS
TAILWATER ELEVATION 969 6



POWERHOUSE UNITS 1 TO 3 OPERATING

POWERHOUSE DISCHARGE 10 500 CFS
PUMPHOUSE INFLOW 550 CFS
TAILWATER ELEVATION 976 8



POWERHOUSE UNITS 1 TO 6 OPERATING

POWERHOUSE DISCHARGE 27 000 CFS
PUMPHOUSE INFLOW 728 CFS
TAILWATER ELEVATION 984.8

LEGEND

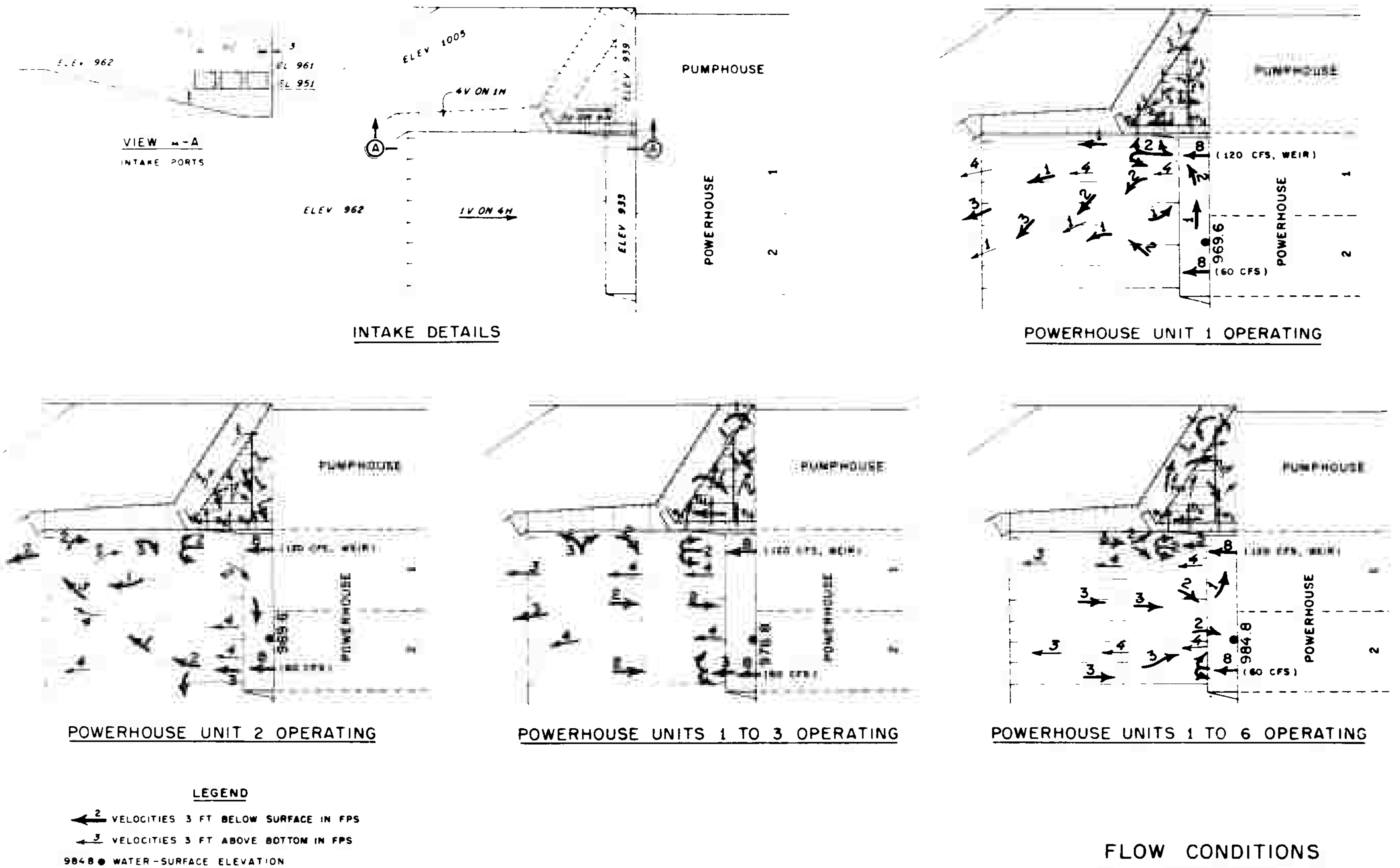
2 VELOCITIES 3 FT BELOW SURFACE IN FPS
3 VELOCITIES 3 FT ABOVE BOTTOM IN FPS

NOTE

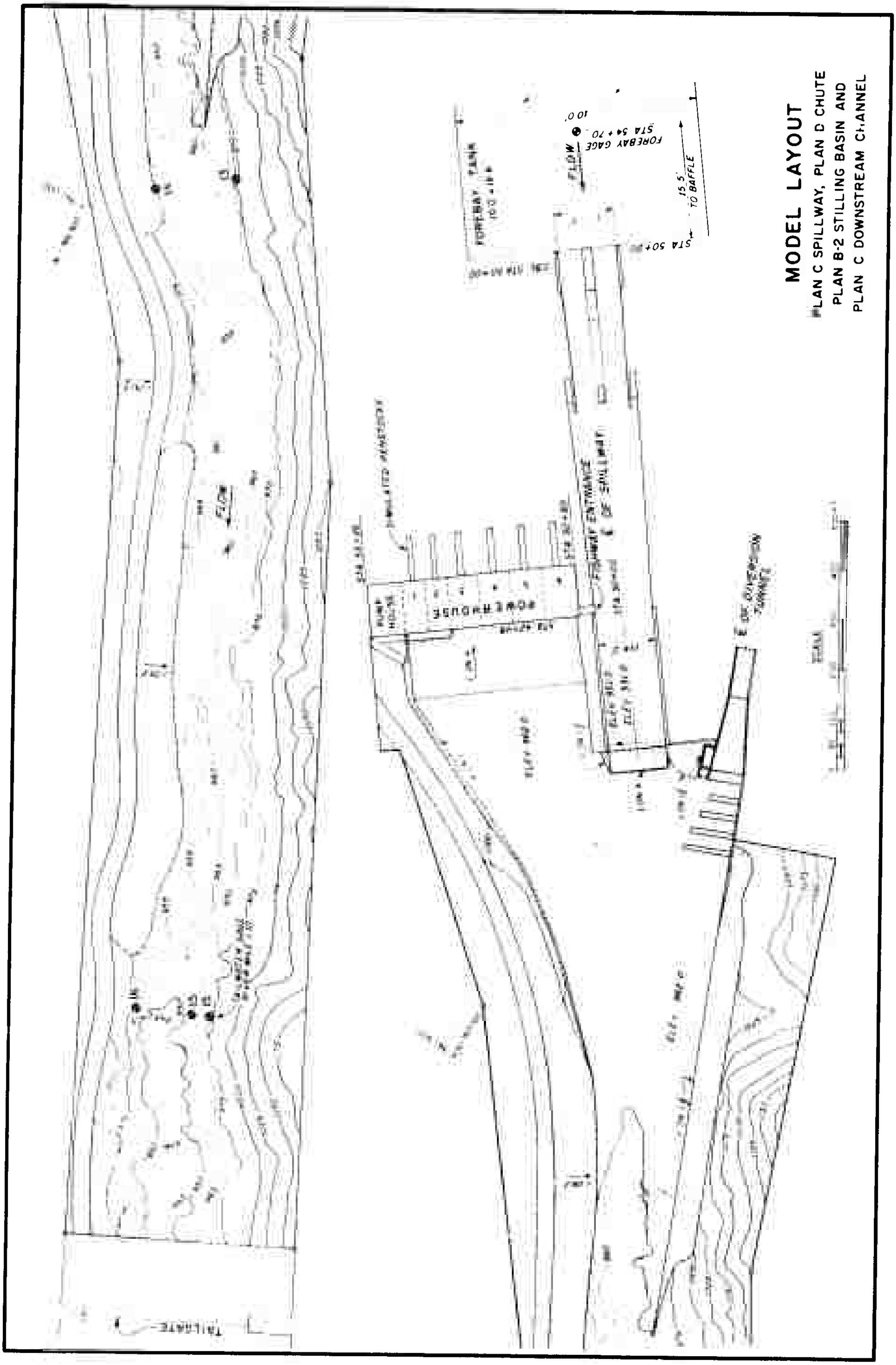
FISHWAY ENTRANCES WERE 2-BY 6-FT SUBMERGED ORIFICES

FLOW CONDITIONS

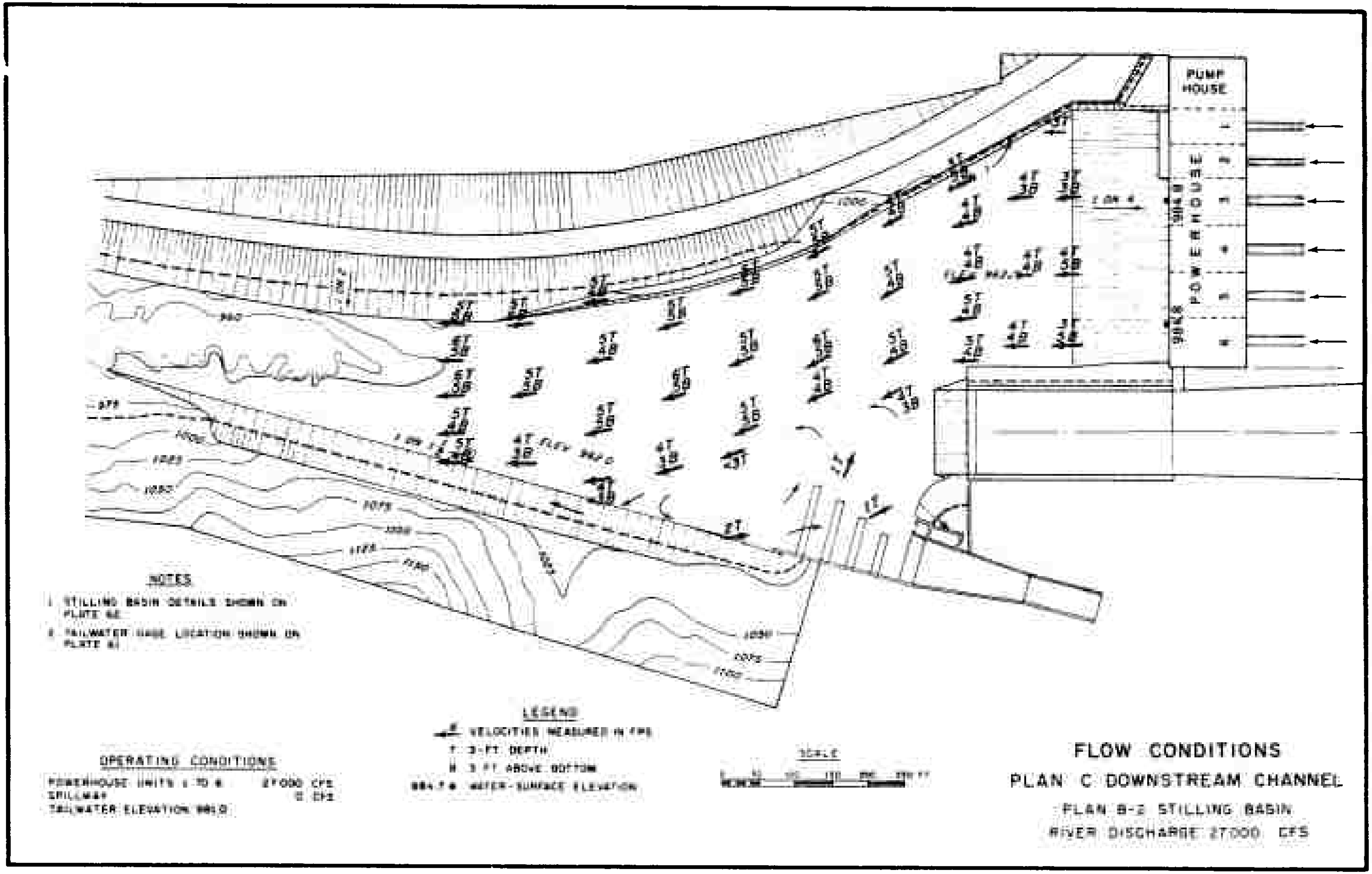
PLAN A PUMP HOUSE INTAKE
TWO FISH ENTRANCES AT UNIT 1



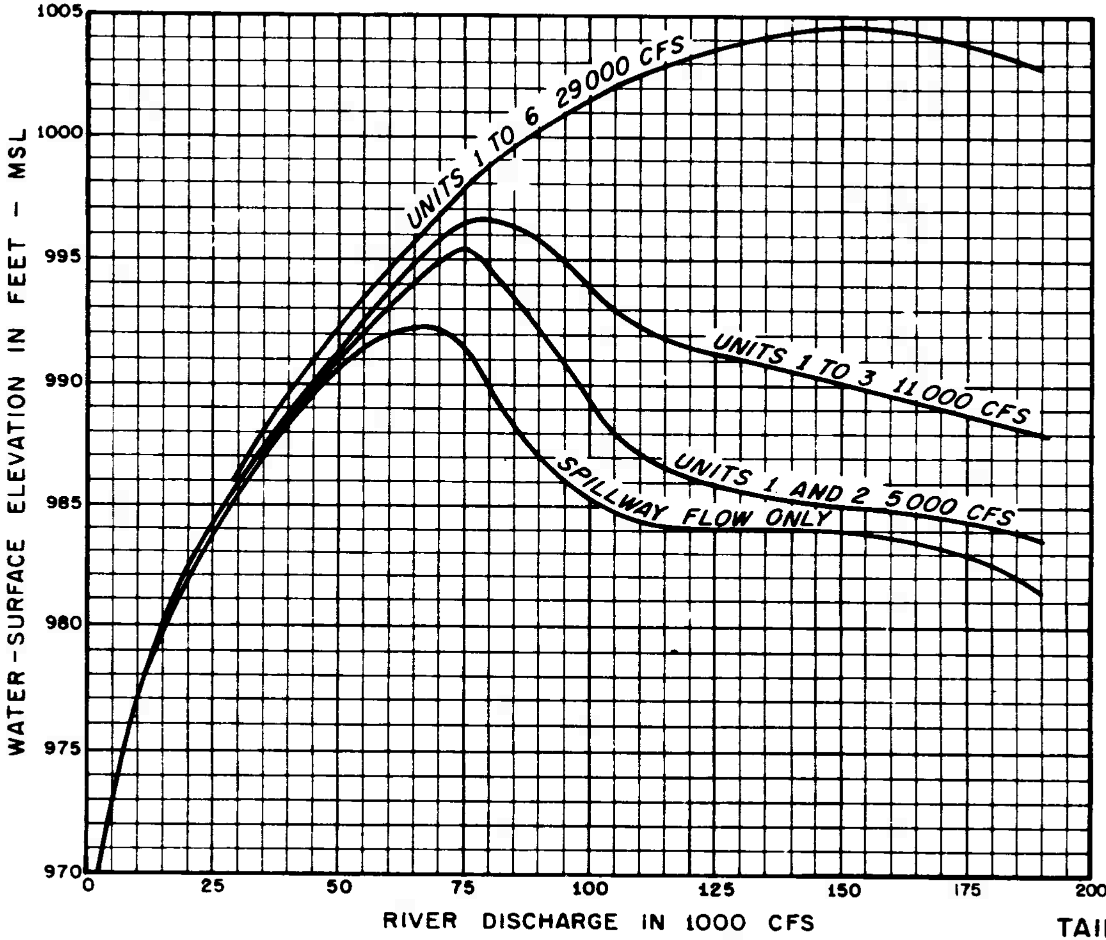
FLOW CONDITIONS
PLAN C PUMPHOUSE INTAKE



MODEL LAYOUT
PLAN C SPILLWAY, PLAN D CHUTE
PLAN B-2 STILLING BASIN AND
PLAN C DOWNSTREAM CHANNEL



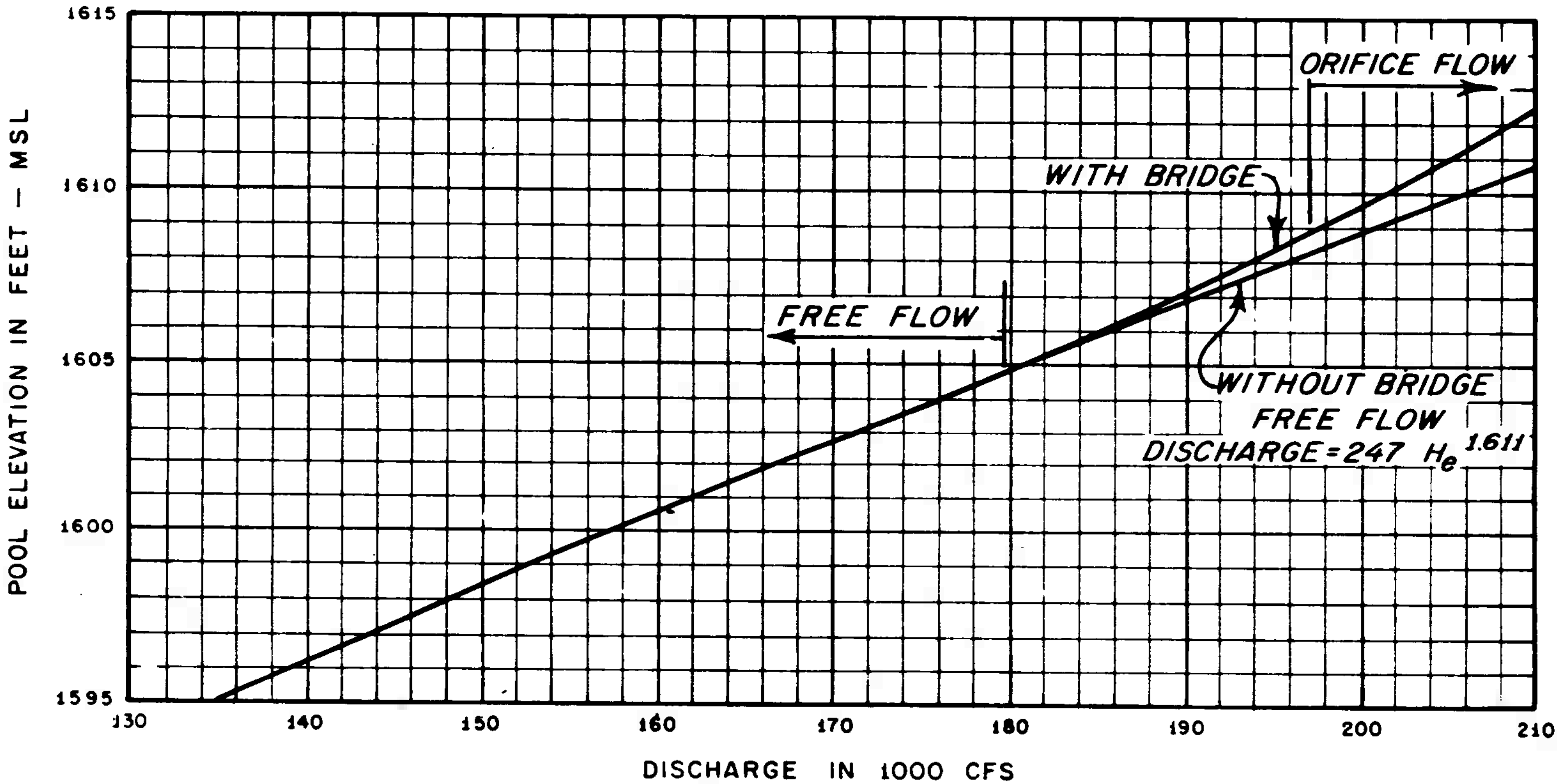
FLOW CONDITIONS
PLAN C DOWNSTREAM CHANNEL
PLAN B-2 STILLING BASIN
RIVER DISCHARGE 27000 CFS



NOTES

1. ALL FLOW THROUGH SPILLWAY AND/OR POWERHOUSE.
2. AVERAGE NATURAL TAILWATER EFFECT FROM CLEARWATER RIVER PLATE 64.
3. DOWNSTREAM CHANNEL AND STILLING BASIN DETAILS SHOW ON PLATES 80 TO 82.

TAILWATER AT POWERHOUSE UNITS 3 AND 6
NATURAL RIVER CONDITIONS
PLAN B-2 STILLING BASIN
PLAN C DOWNSTREAM CHANNEL



NOTES

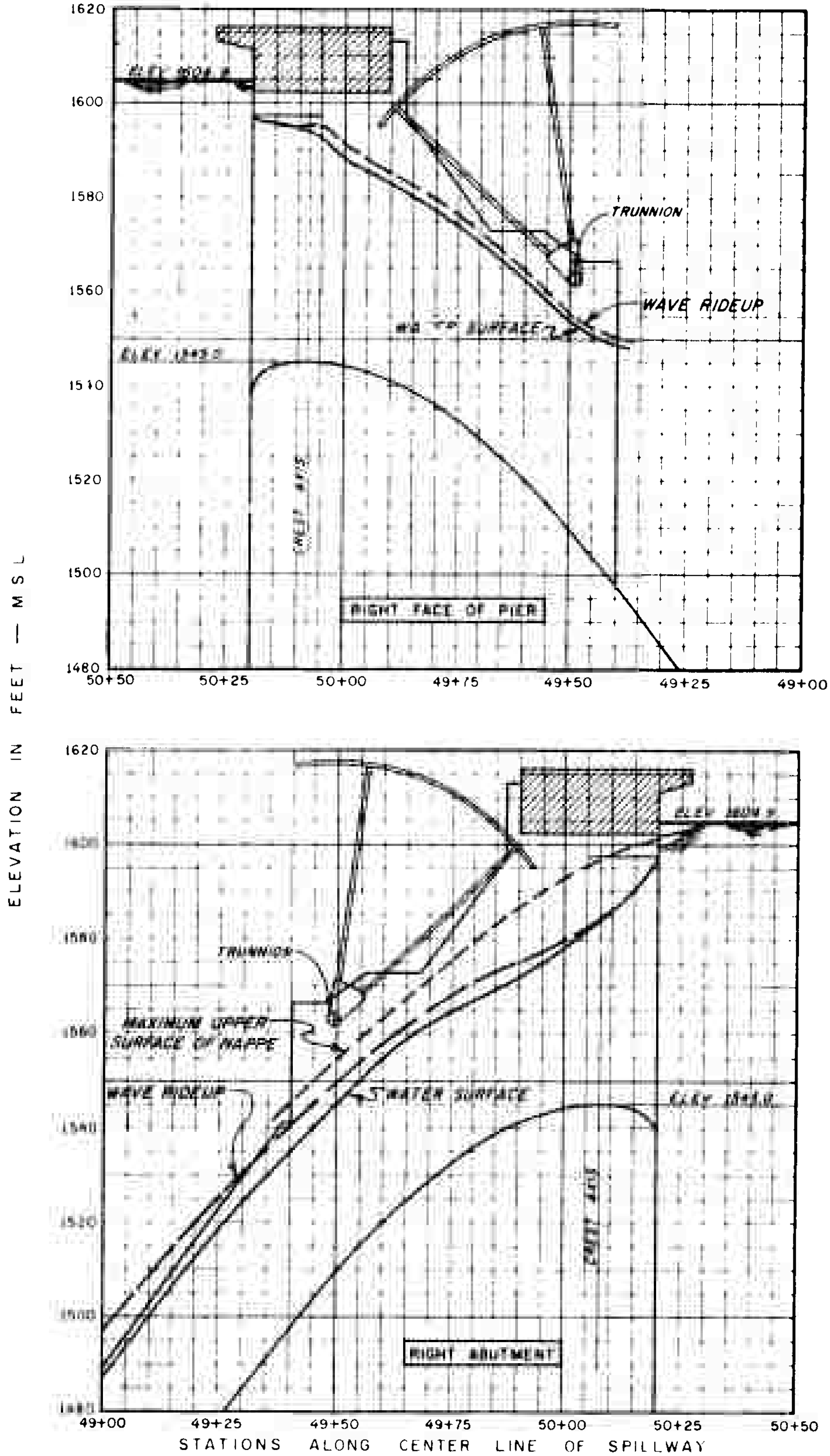
1. DETAILS OF SPILLWAY SHOWN ON PLATE 3.
2. FREE FLOW DISCHARGE RATING FOR LOWER HEADS SHOWN ON PLATE 44.

RATING CURVE FOR FREE FLOW

PLAN C SPILLWAY

CONTRACT PLAN SPILLWAY BRIDGE

POOL ELEV 1595.0 TO 1612.5

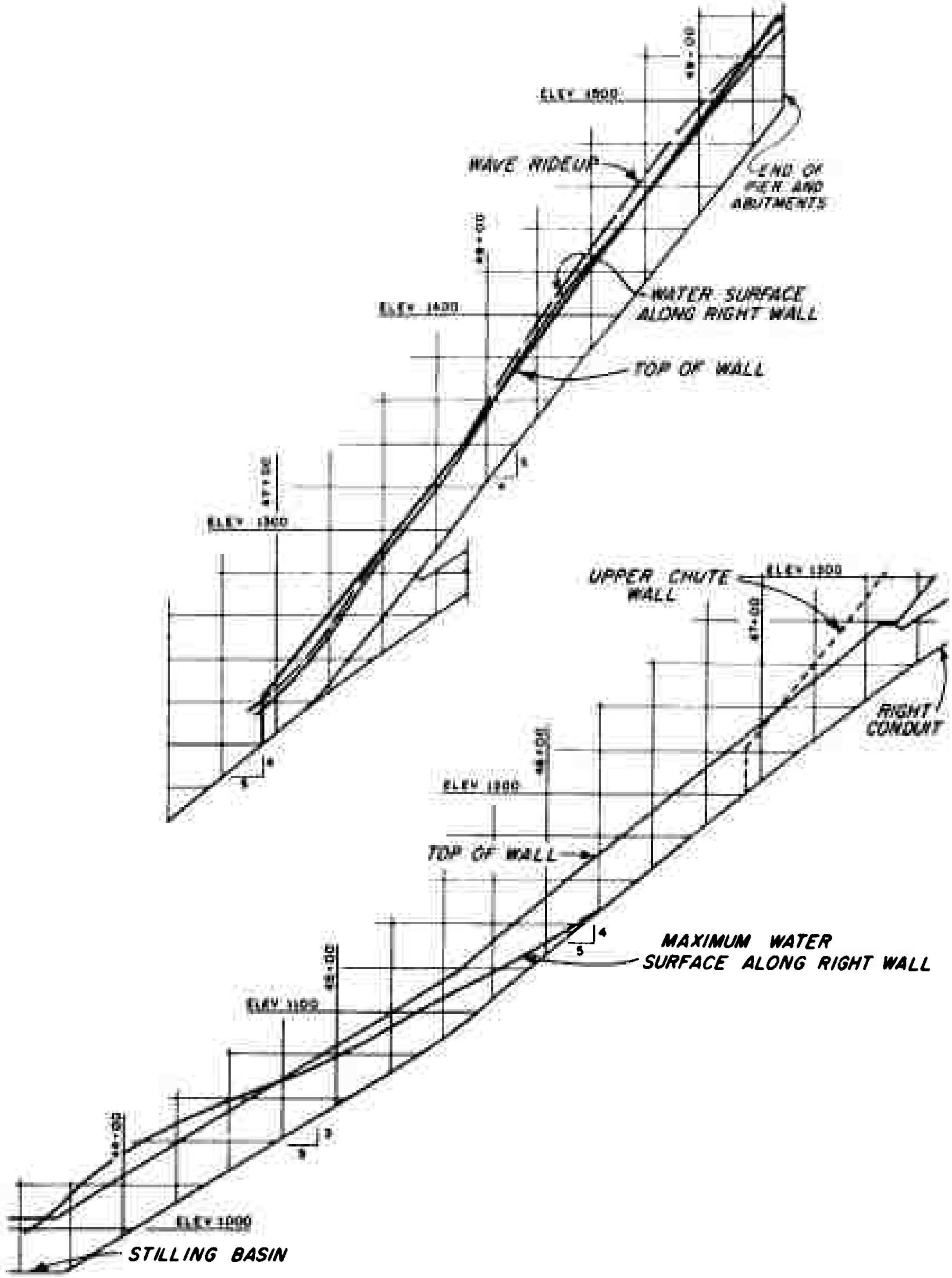


WATER-SURFACE PROFILES

PLAN C SPILLWAY

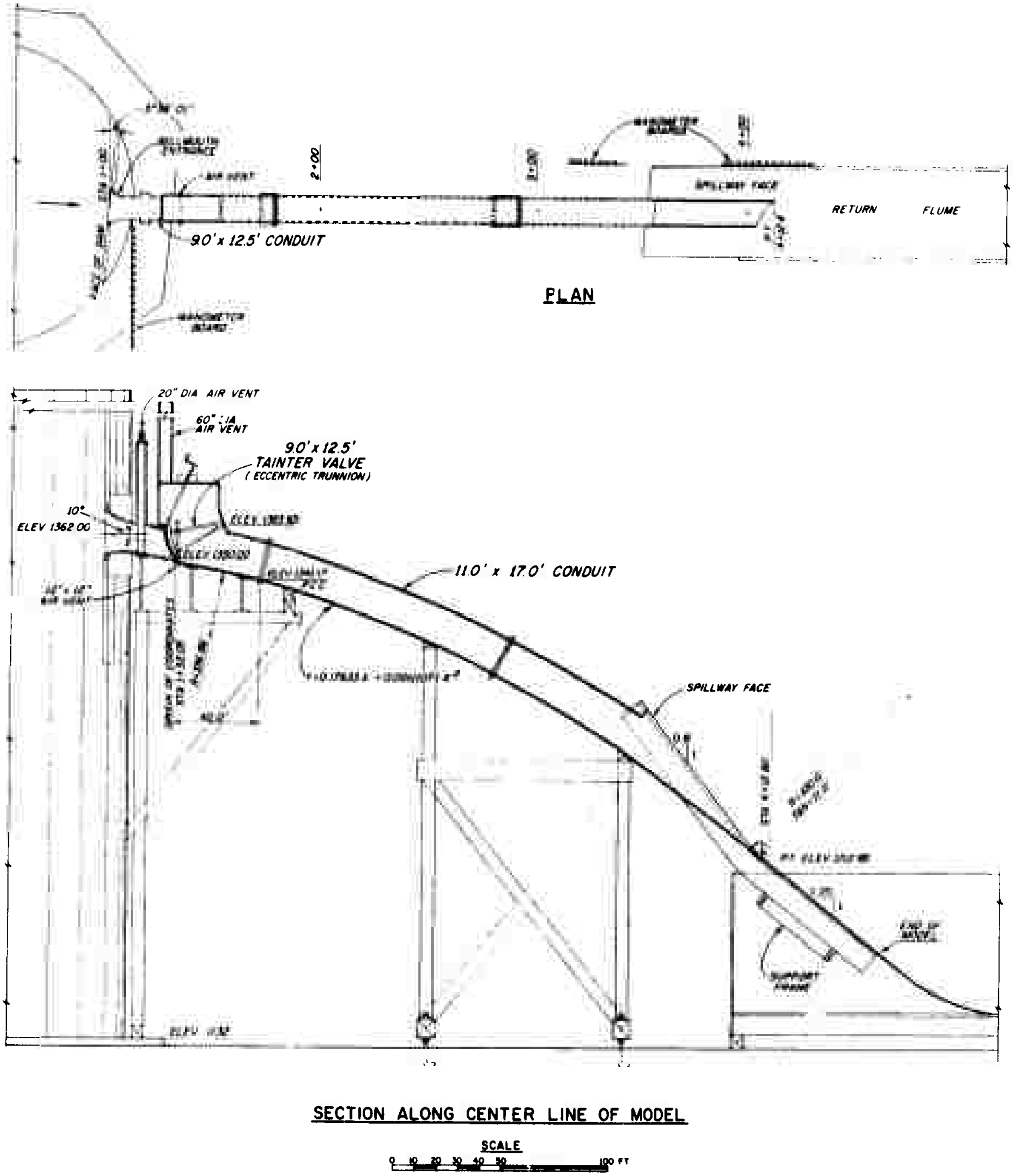
CONTRACT PLAN SPILLWAY BRIDGE

SPILLWAY DISCHARGE 181000 CFS



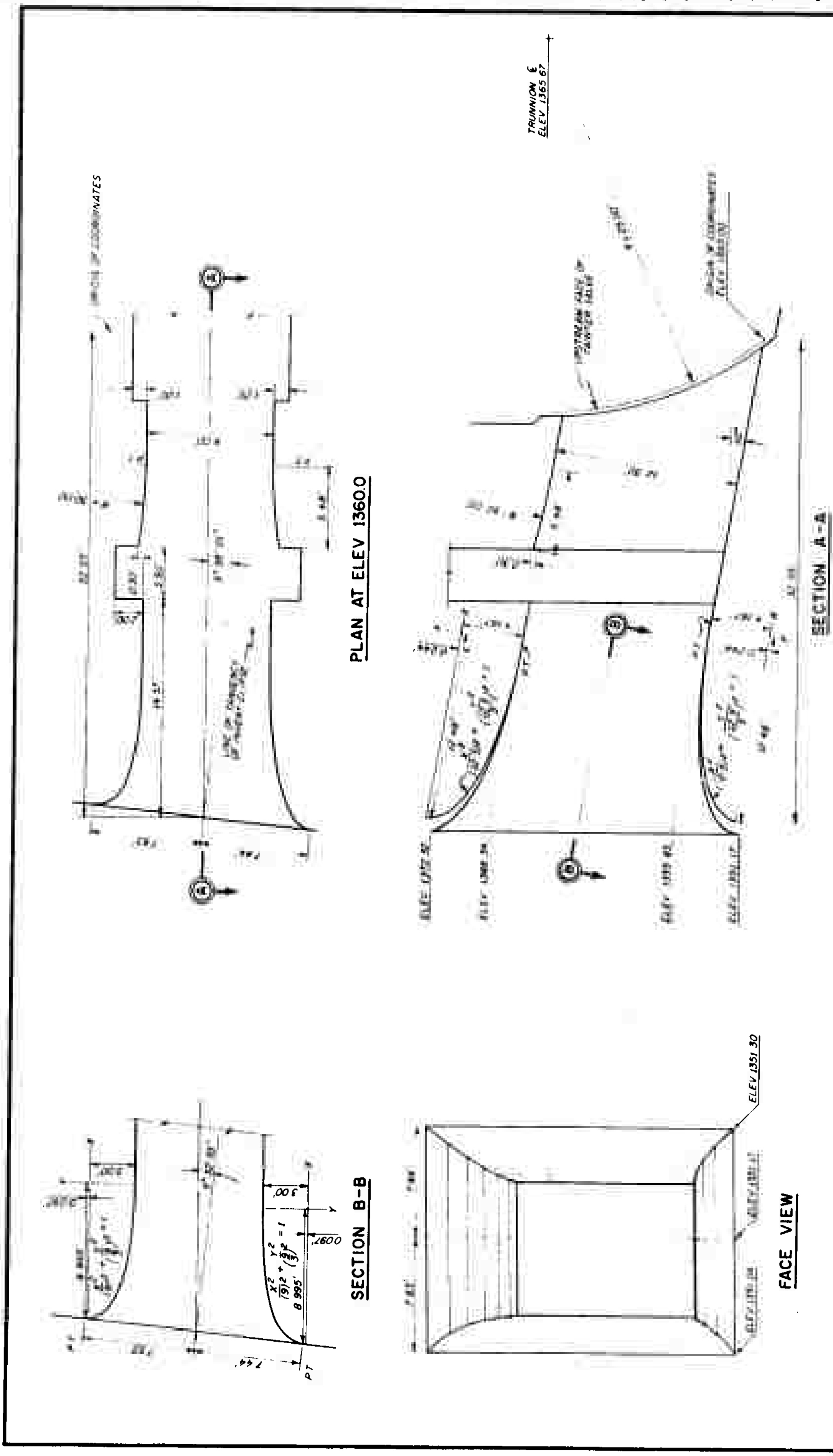
NOTE
CHUTE DETAILS SHOWN ON PLATE 71.

WATER-SURFACE PROFILES
PLAN C SPILLWAY
CONTRACT PLAN SPILLWAY BRIDGE
STATION 49+35 TO 43+55
SPILLWAY DISCHARGE 181 000 CFS

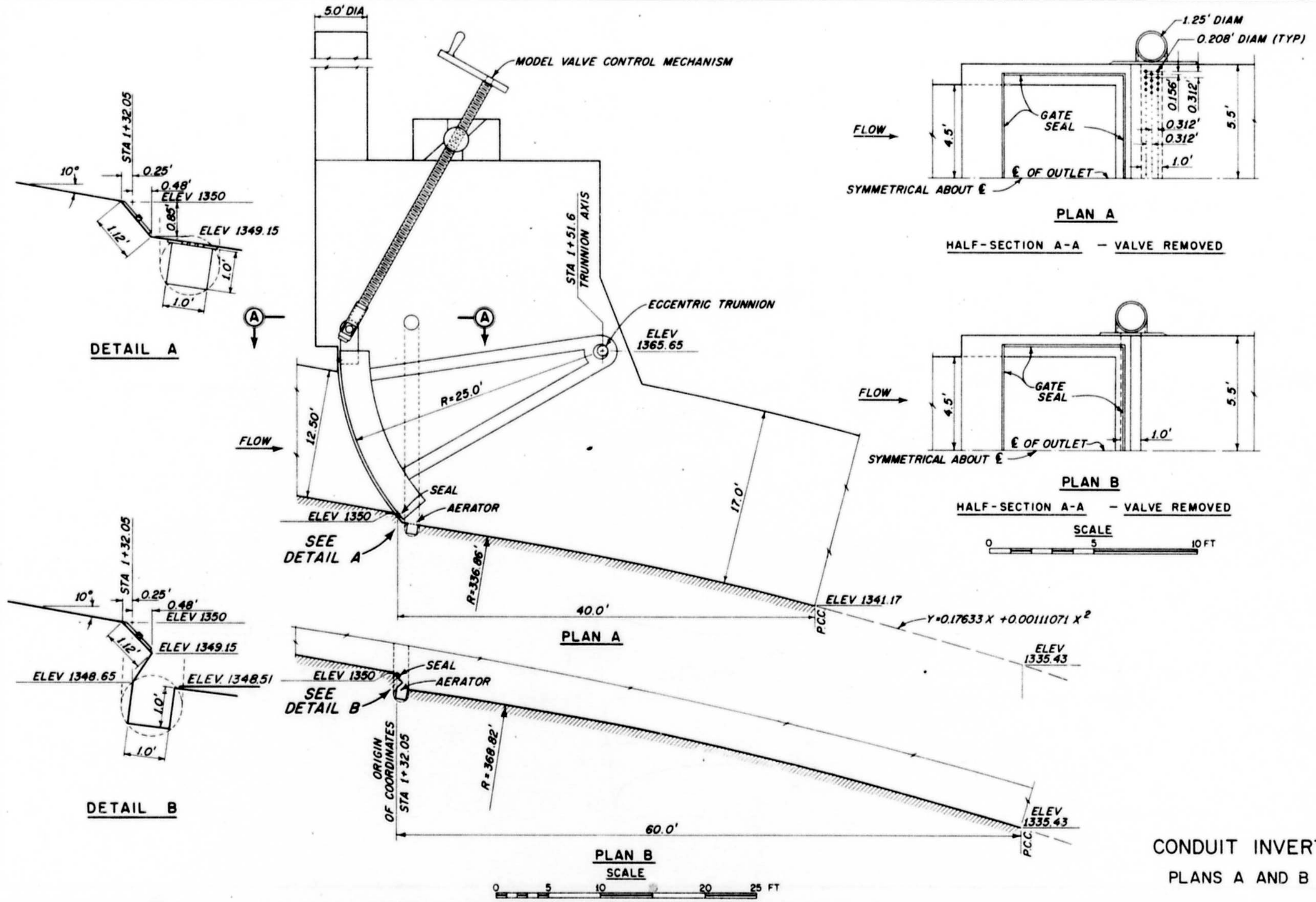


MODEL LAYOUT

PLAN A RIGHT CONDUIT
ORIGINAL DESIGN



PLAN A RIGHT CONDUIT ENTRANCE
(ORIGINAL DESIGN)



CONDUIT INVERT
PLANS A AND B

PLATE 89

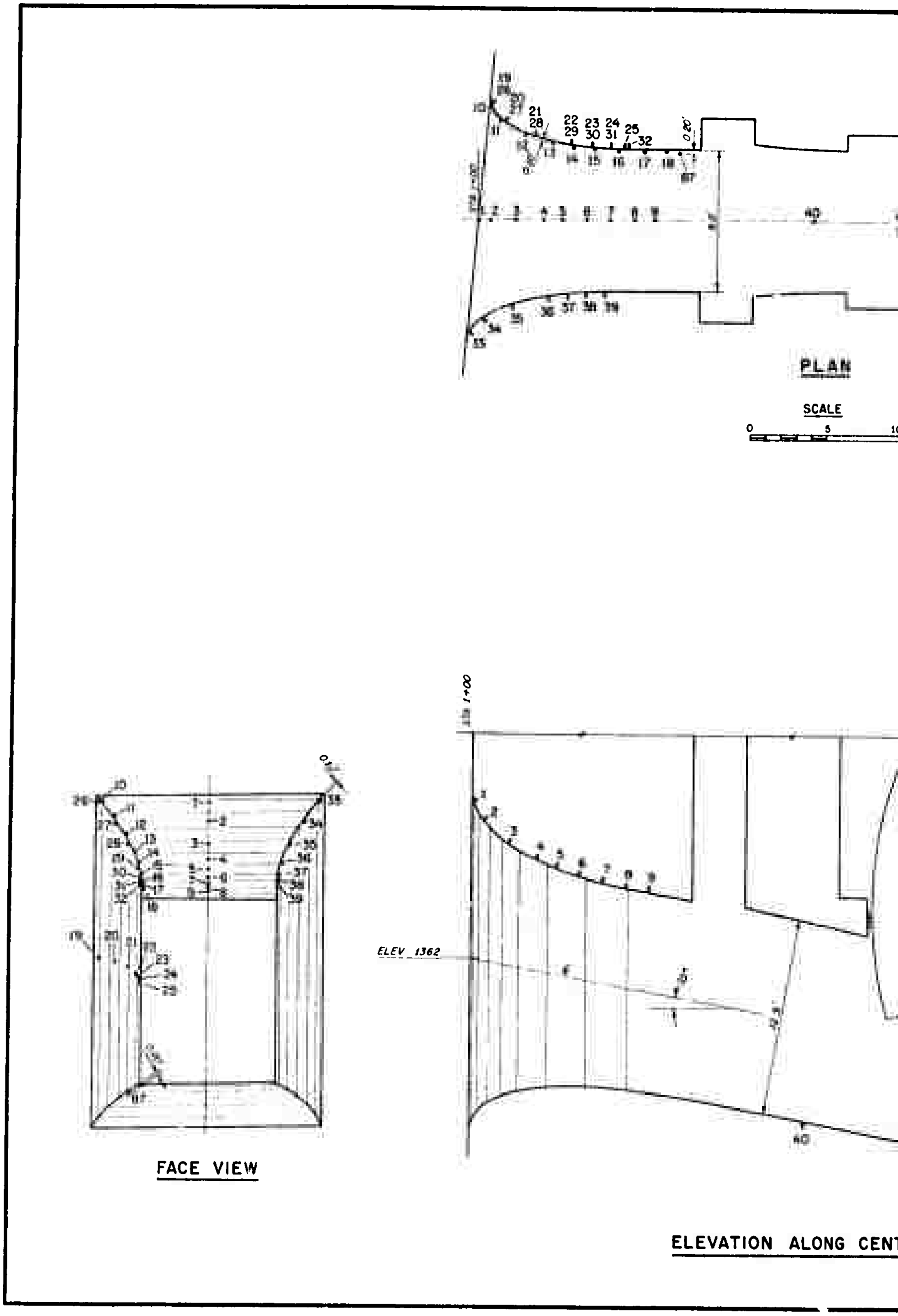
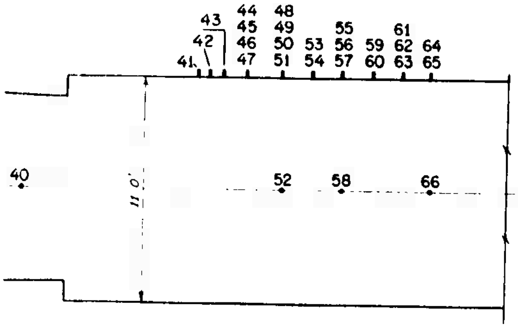


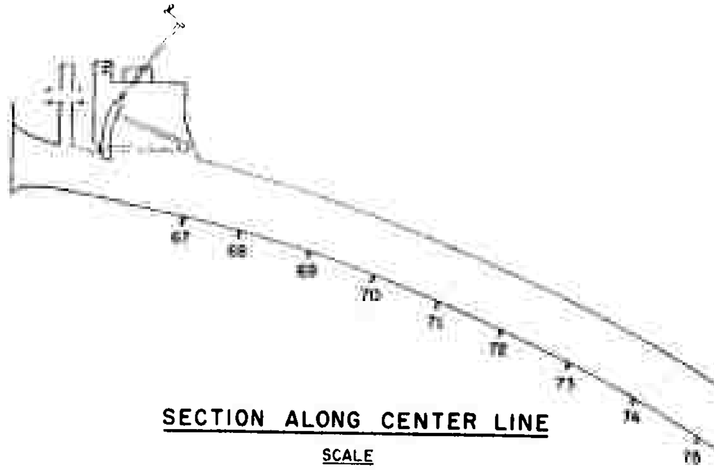
PLATE 90



PLAN

SCALE

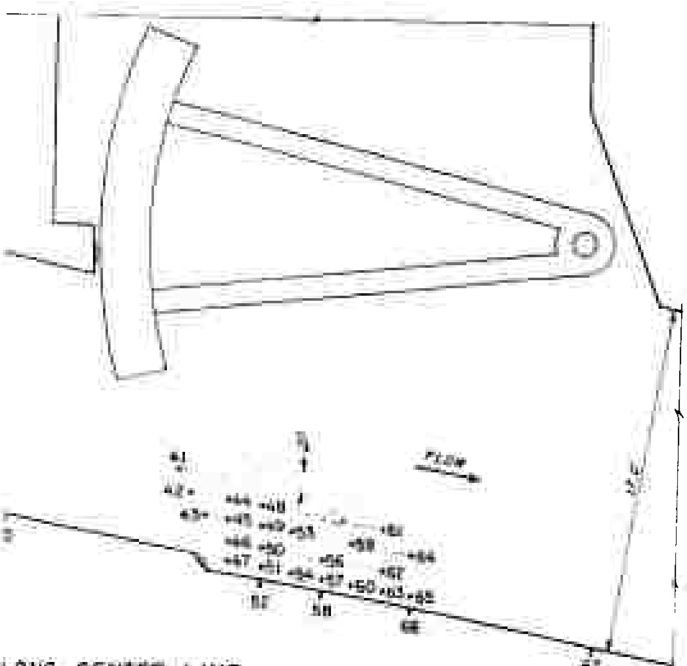
5 10 FT



SECTION ALONG CENTER LINE

SCALE

0 10 20 30 40 50 FT



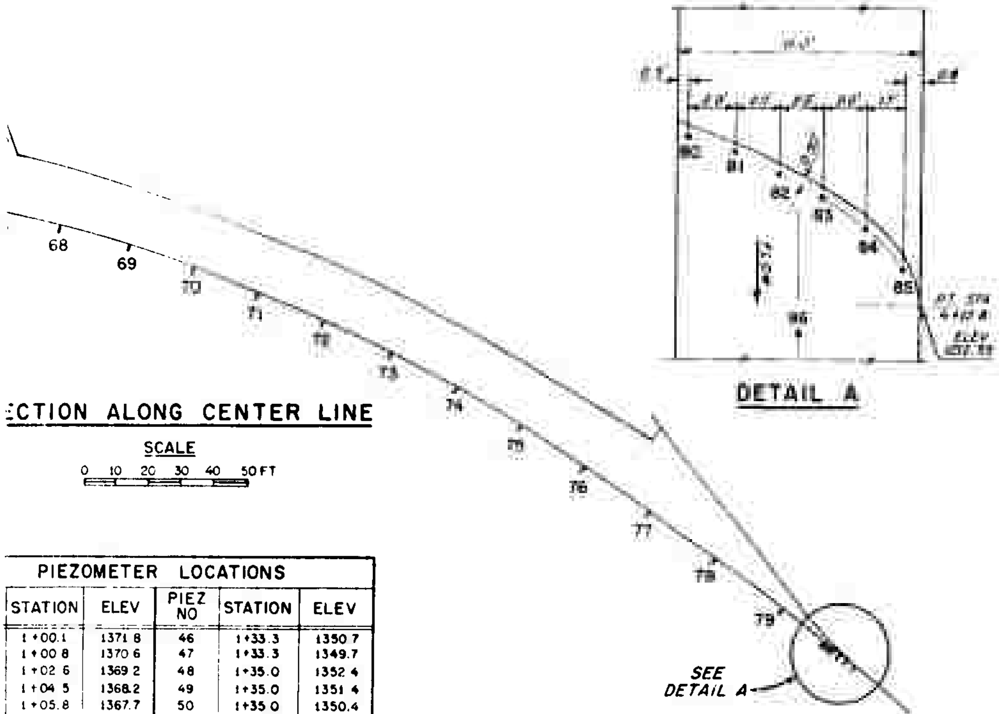
LONG CENTER LINE

PIEZOMETER LOCATIONS					
PIEZ NO	STATION	ELEV	PIEZ NO	STATION	ELEV
1	1+00 1	1371 8	46	1+33 3	1350.7
2	1+00 8	1370 6	47	1+33.3	1349.7
3	1+02 6	1369 2	48	1+35.0	1352 4
4	1+04 5	1368.2	49	1+35.0	1351 4
5	1+05.8	1367.7	50	1+35 0	1350.4
6	1+07 1	[illegible]	[illegible]	[illegible]	1349.4
7	1+08.9	1366 8	52	1+35.0	1348.8
8	1+10 5	[illegible]	[illegible]	[illegible]	1351 2
9	1+11 8	1366 2	54	1+36.5	1349.2
10	1+00 8	1371.7	55	1+38.0	1351 9
11	1+01.4	1370.5	56	1+38.0	1349 9
12	1+03.1	1369 1	57	1+38.0	1348.9
13	1+04.9	1368.1	58	1+38.0	1348 3
14	1+06.3	1367.5	59	1+39 5	1350 6
15	1+07.7	1367.1	60	1+39.5	1348 6
16	1+09.3	1366.7	61	1+41.0	1351 4
17	1+10.9	1366.3	62	1+41 0	1349 4
18	1+12.3	1366.1	63	1+41 0	1348.4
19	1+00.9	1361.9	64	1+42.5	1350.1
20	1+01 7	1361.6	65	1+42 5	1348.1
21	1+03.8	1361.2	66	1+42 5	1347 6
22	1+06 2	1360.8	67	1+52.0	1345.8
23	1+07.6	1360 6	68	1+70 0	1341.7
24	1+08.7	1360.4	69	1+92.1	1335.4
25	1+09 7	1360.3	70	2+12 1	1328.3
26	1+00.9	1371 2	71	2+32 1	1321.3
27	1+01.7	1370 0	72	2+52.1	1312.9
28	1+03 7	1368.6	73	2+72 1	1303.6
29	1+06 1	1367 5	74	2+92 1	1293.4
30	1+07.6	1367.1	75	3+12 1	1282.3
31	1+08.7	1366 7	76	3+32.1	1270.3
32	1+09.9	1366 4	77	3+52 1	1257.5
33	0+99.5	1371 5	78	3+72.1	1243.7
34	1+00.4	1370 4	79	3+92.1	1229.1
35	1+02 3	1369.0	80	4+04.5	1219.4
36	1+04 7	1367 8	81	4+05.4	1218.7
37	1+06.1	1367 3	82	4+06 5	1217.9
38	1+07 2	1367 0	83	4+07.8	1216 8
39	1+08 5	1366.7	84	4+09 6	1215 4
40	1+22 0	1351 8	85	4+11 9	1213.7
41	1+30 9	1354.2	86	4+14 1	1212.0
42	1+31.5	1353 1	87	1+13 3	1353 3
43	1+32.2	1351 9			
44	1+33 3	1352 7			
45	1+33 3	1351 7			

DET

2

3a



ECTION ALONG CENTER LINE

SCALE

0 10 20 30 40 50 FT

PIEZOMETER LOCATIONS				
STATION	ELEV	PIEZ NO	STATION	ELEV
1+00.1	1371 8	46	1+33.3	1350 7
1+00 8	1370 6	47	1+33.3	1349.7
1+02 6	1369 2	48	1+35.0	1352 4
1+04 5	1368.2	49	1+35.0	1351 4
1+05.8	1367.7	50	1+35 0	1350.4
1+07 4	1367 1	51	1+35 0	1349 4
1+08 9	1366 8	52	1+35.0	1348.8
1+10 5	1366 5	53	1+36.5	1351.2
1+11 8	1366 2	54	1+36.5	1349.2
1+00 8	1371 7	55	1+38.0	1351 9
1+01 4	1370 5	56	1+38 0	1349.9
1+03 1	1369 1	57	1+38.0	1348 9
1+04 9	1368 1	58	1+38.0	1348 3
1+06 3	1367 5	59	1+39 5	1350.6
1+07 7	1367.1	60	1+39.5	1348 6
1+09 3	1366.7	61	1+41.0	1351.4
1+10 9	1366.3	62	1+41.0	1349.4
1+12 3	1366.1	63	1+41 0	1348.4
1+00 9	1361.9	64	1+42 5	1350.1
1+01 7	1361.6	65	1+42 5	1348 1
1+03 8	1361 2	66	1+42 5	1347.6
1+06 2	1360.8	67	1+52 0	1345.8
1+07 6	1360 6	68	1+70 0	1341 7
1+08 7	1360.4	69	1+92 1	1335 4
1+09.7	1360.3	70	2+12 1	1328.3
1+00.9	1371.2	71	2+32.1	1321.3
1+01 7	1370 0	72	2+52.1	1312.9
1+03 7	1368.6	73	2+72 1	1303 6
1+06 1	1367.5	74	2+92 1	1293 4
1+07 6	1367 1	75	3+12.1	1282 3
1+08 7	1366 7	76	3+32.1	1270.3
1+09.9	1366.4	77	3+52 1	1257.5
0+99.5	1371 5	78	3+72.1	1243.7
1+00.4	1370.4	79	3+92.1	1229.1
1+02 3	1369.0	80	4+04 5	1219 4
1+04 7	1367.8	81	4+05.4	1218.7
1+06 1	1367.3	82	4+06 5	1217.9
1+07 2	1367 0	83	4+07.8	1216 8
1+08 5	1366 7	84	4+09 6	1215 4
1+22 0	1351 8	85	4+11 9	1213 7
1+30.9	1354 2	86	4+14 1	1212.0
1+31 5	1353 1	87	1+13 3	1353.3
1+32 2	1351 9			
1+33 3	1352 7			
1+33 3	1351 7			

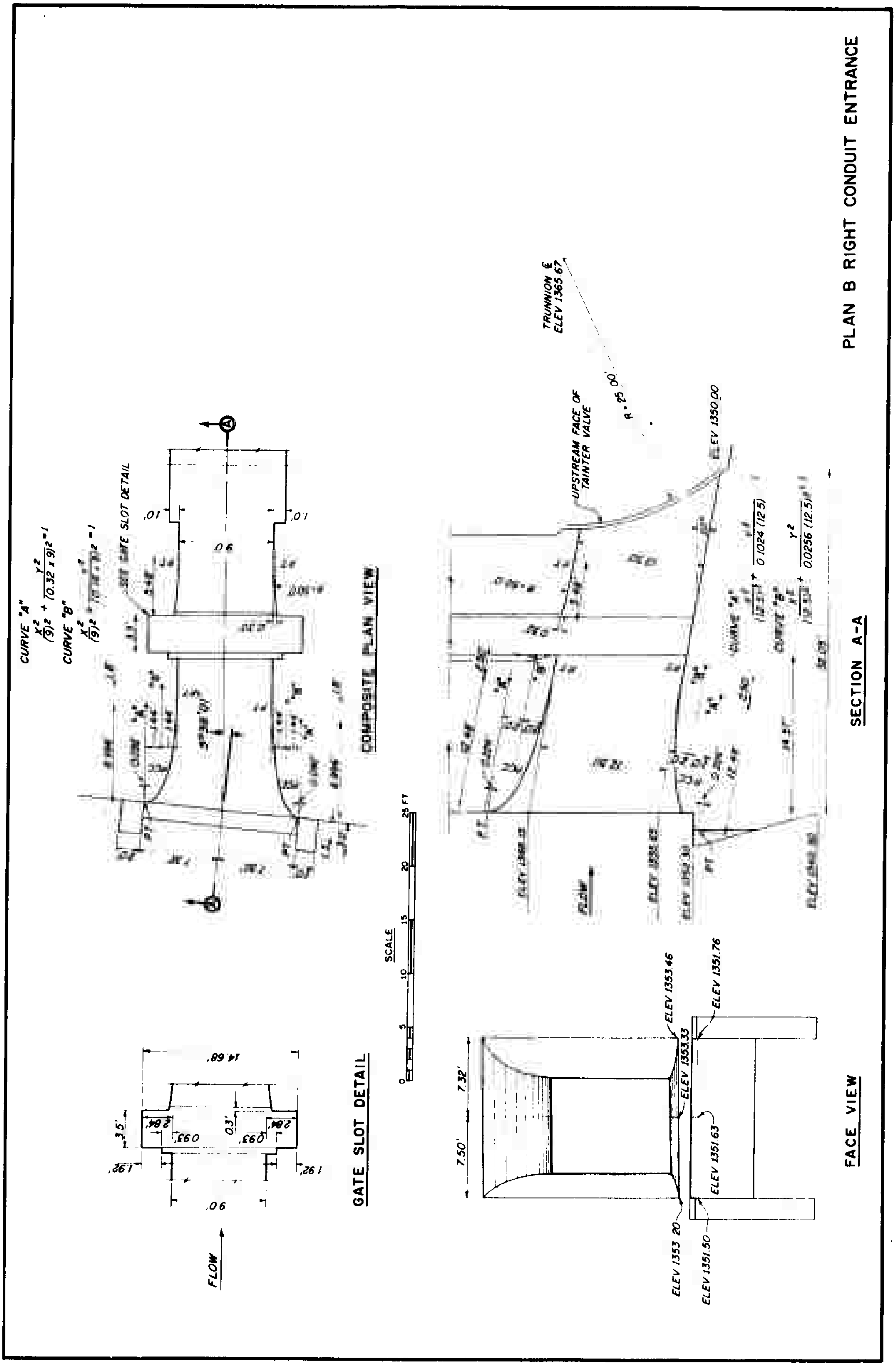
NOTE

DETAILS OF ENTRANCE ARE SHOWN ON PLATE 88

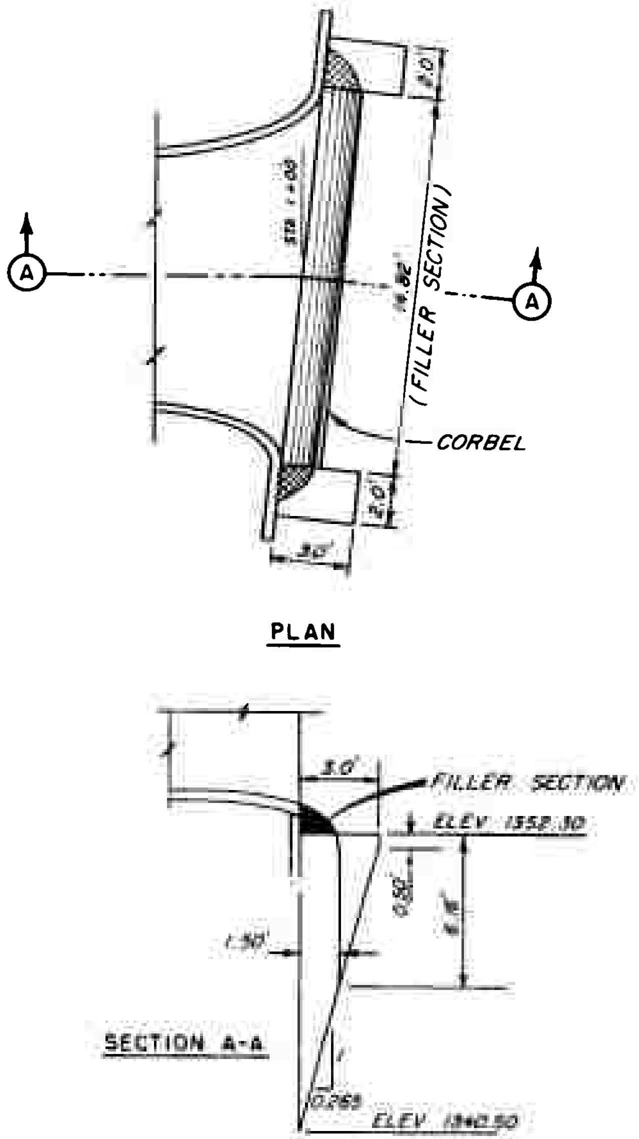
PIEZOMETER LOCATIONS

PLAN A RIGHT CONDUIT
ORIGINAL DESIGN

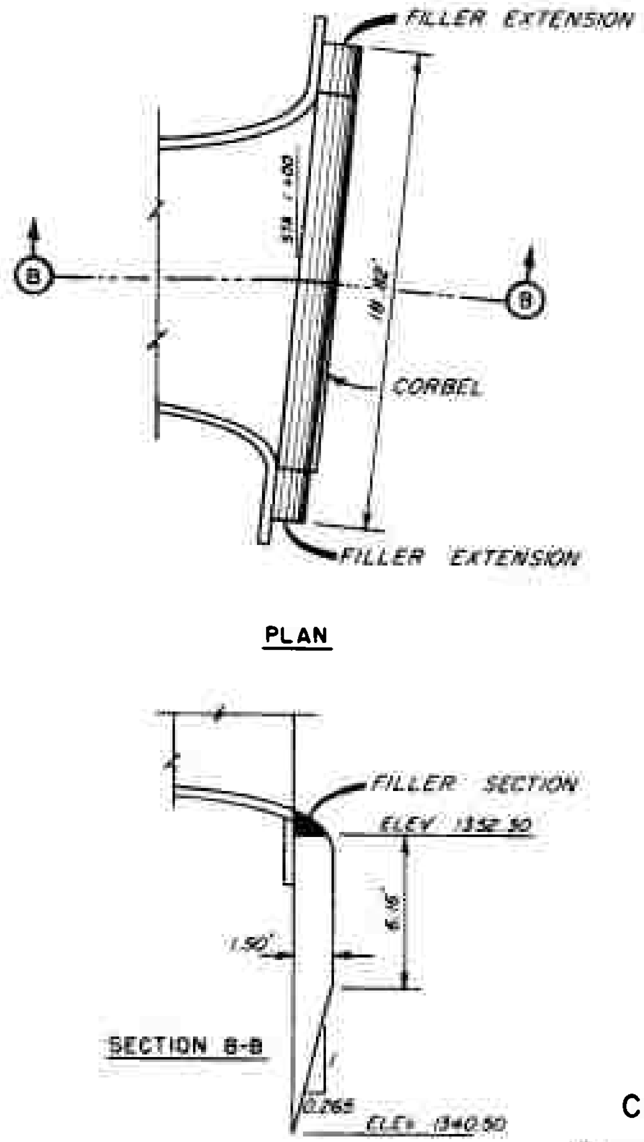
3 of 3



PLAN B RIGHT CONDUIT ENTRANCE
CURVE "A"
$\frac{X^2}{(9)^2} + \frac{Y^2}{(0.32 \times 9)^2} = 1$
CURVE "B"
SEE GATE SLOT DETAIL
COMPOSITE PLAN VIEW
TRUNNION ℄
ELEV 1365.67
R = 25.00'
UPSTREAM FACE OF TAINTER VALVE
ELEV 1350.00
$\frac{Y^2}{0.1024\ (12.5)}$
$\frac{Y^2}{0.0256\ (12.5)}$
SECTION A-A
FLOW
SCALE
0
5
10
15
20
25 FT
14.68'
3.5'
0.3'
2.84'
0.93'
1.92'
9.0'
GATE SLOT DETAIL
FLOW
7.50'
7.32'
ELEV 1353.46
ELEV 1351.76
ELEV 1353.33
ELEV 1351.63
ELEV 1353.20
ELEV 1351.50
FACE VIEW



PLAN B-2



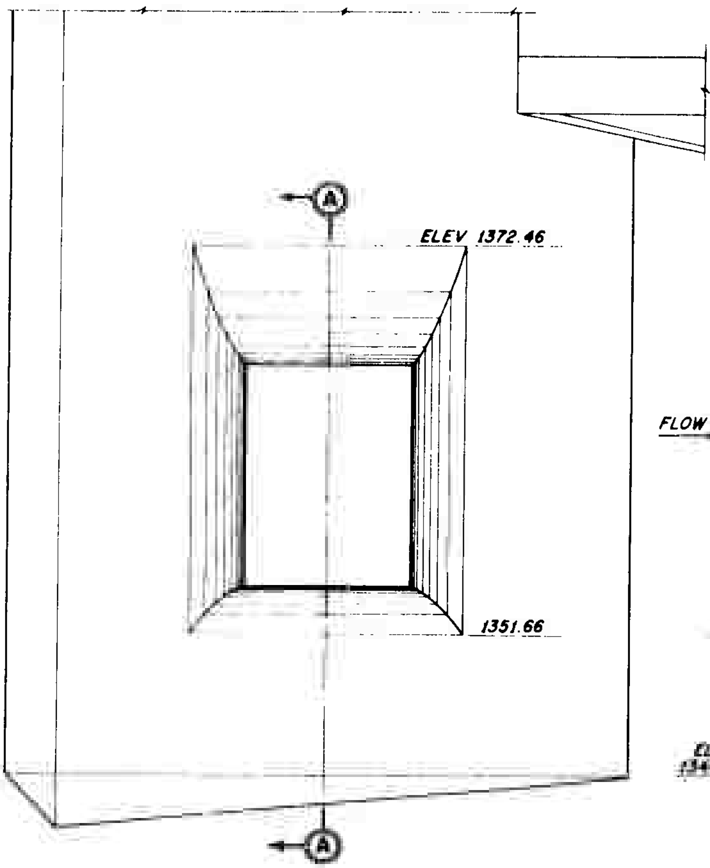
PLAN B-3

NOTE

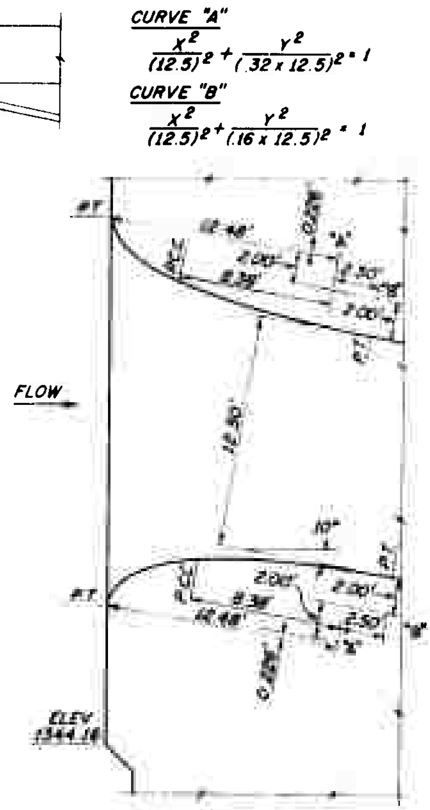
DETAILS OF PLAN B ENTRANCE ARE SHOWN ON PLATE 91.

CORBEL MODIFICATIONS

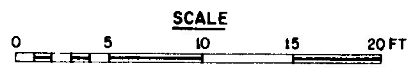
PLAN B RIGHT CONDUIT ENTRANCE

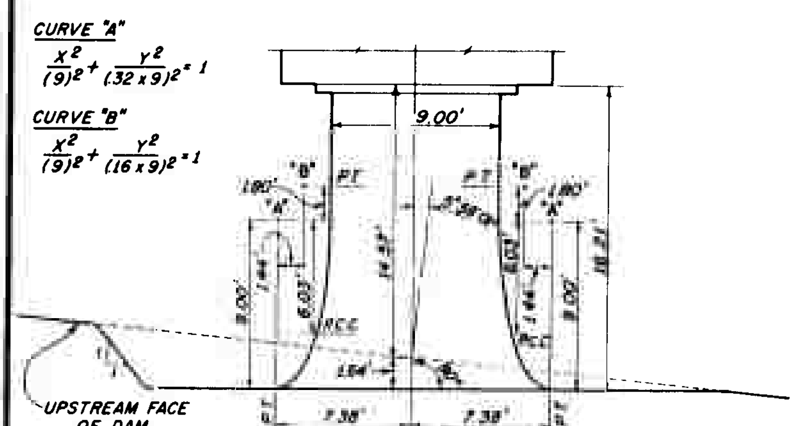


FACE VIEW OF CONDUIT



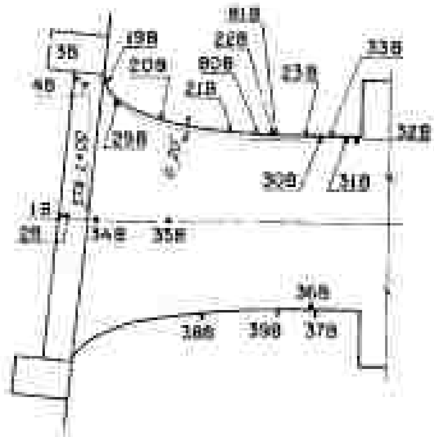
SECTION A-A



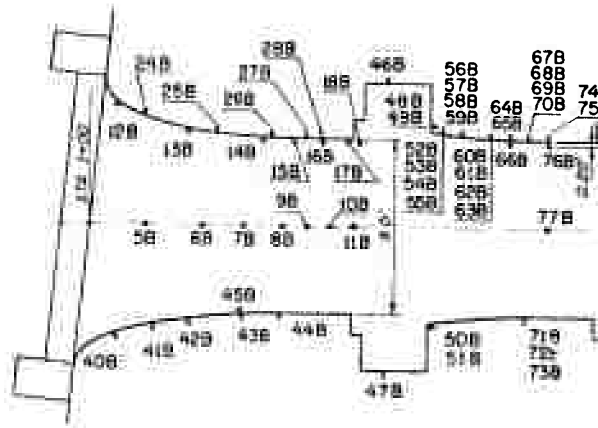


COMPOSITE PLAN VIEW

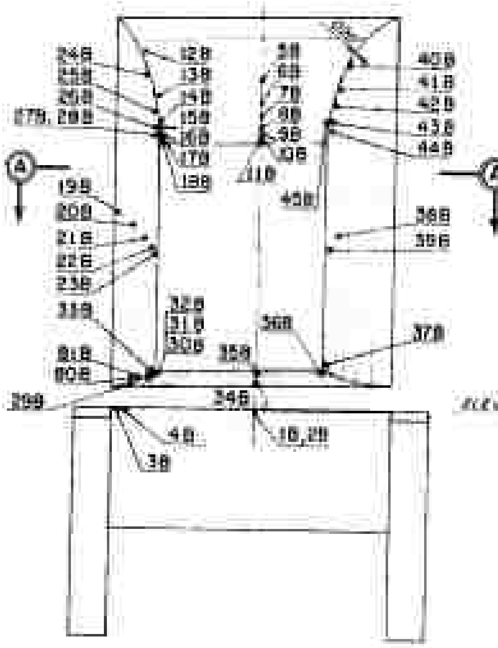
PLAN C RIGHT CONDUIT ENTRANCE



SECTION A-A

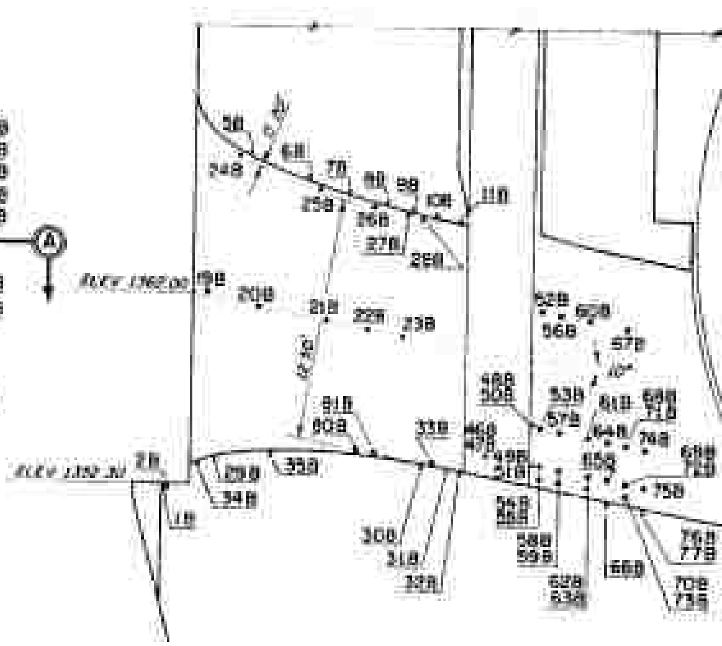


PLAN

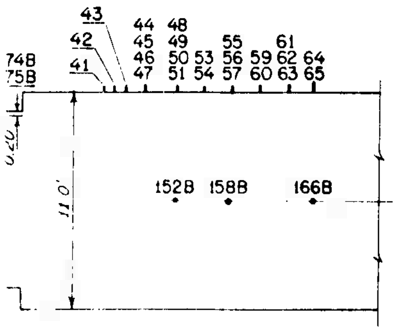


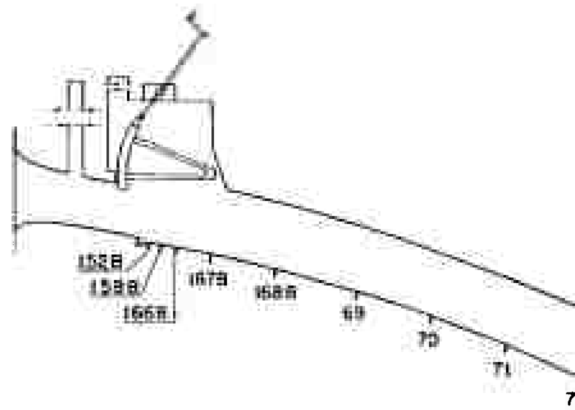
FACE VIEW

SCALE



ELEVATION ALO



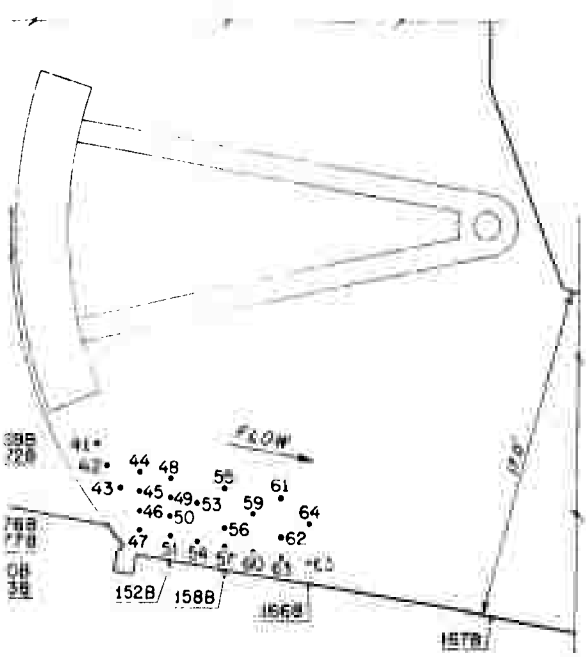


SECTION ALONG CENTER LI

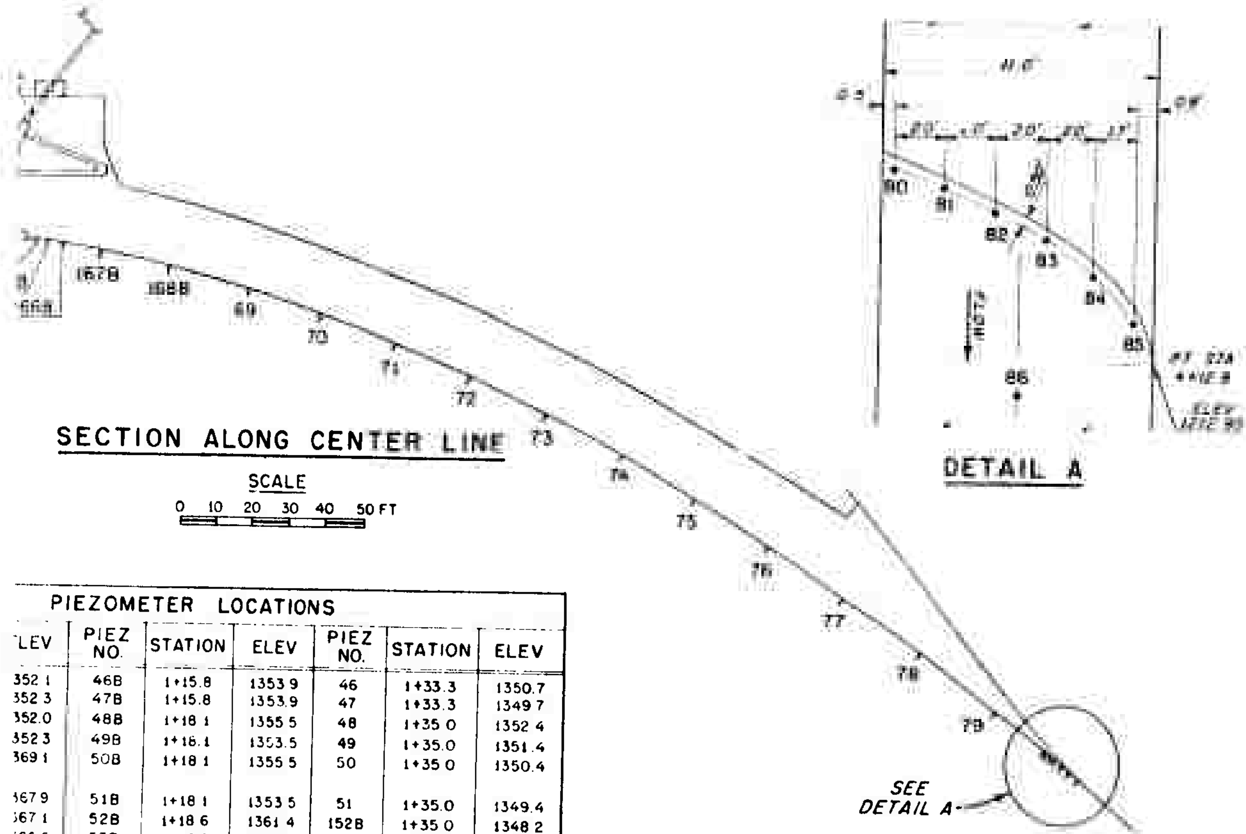
SCALE

0 10 20 30 40 50 FT

PIEZOMETER LOCATIONS							
PIEZ NO.	STATION	ELEV	PIEZ NO.	STATION	ELEV	PIEZ NO.	STATIO
1B	0+98.6	1352.1	46B	1+15.8	1353.9	46	1+33.3
2B	0+98.8	1352.3	47B	1+15.8	1353.9	47	1+33.3
3B	0+99.2	1352.0	48B	1+18.1	1355.5	48	1+35.0
4B	0+99.7	1352.3	49B	1+18.1	1353.5	49	1+35 0
5B	1+02.9	1369.1	50B	1+18 1	1355.5	50	1+35 0
6B	1+05 9	1367.9	51B	1+18.1	1353.5	51	1+35.0
7B	1+08 2	1367.1	52B	1+18.6	1361.4	152B	1+35.0
8B	1+10.3	1366.6	53B	1+18.6	1355.4	53	1+36.5
9B	1+11 7	1366.3	54B	1+18.6	1353.4	54	1+36 5
10B	1+12.9	1366.1	55B	1+18.6	1352.8	55	1+38.0
11B	1+14.2	1365.9	56B	1+19 6	1361.2	56	1+38.0
12B	1+01.4	1370.5	57B	1+19.6	1355.2	57	1+38.0
13B	1+05.1	1368.2	58B	1+19.6	1353.2	158B	1+38.0
14B	1+09.2	1366.9	59B	1+19.6	1352.6	59	1+39.5
15B	1+10.9	1366.5	60B	1+21.1	1360.9	60	1+39.5
16B	1+12 4	1366.1	61B	1+21.1	1354.9	61	1+41.0
17B	1+13.8	1365.9	62B	1+21.1	1352 9	62	1+41.0
18B	1+14.4	1365.8	63B	1+21.1	1352.3	63	1+41.0
19B	1+00.8	1362.1	64B	1+22 1	1354.8	64	1+42.5
20B	1+03.7	1361.5	65B	1+22.1	1352.8	65	1+42.5
21B	1+07.4	1360.8	66B	1+22.1	1351.8	166B	1+42.5
22B	1+09.7	1360.3	67B	1+23.1	1360.6	167B	1+52 0
23B	1+11.6	1360.0	68B	1+23.1	1354.6	168B	1+70.0
24B	1+02.8	1369.2	69B	1+23.1	1352.6	69	1+92.1
25B	1+06.7	1367.3	70B	1+23.1	1352.0	70	2+12.1
26B	1+09.7	1366.5	71B	1+23.1	1354.6	71	2+32.1
27B	1+11.5	1366.1	72B	1+23.1	1352.6	72	2+52 1
28B	1+12.4	1366.1	73B	1+23 1	1352.0	73	2+72.1
29B	1+01.3	1353 5	74B	1+24.1	1354.4	74	2+92.1
30B	1+12.3	1353.4	75B	1+24.1	1352 4	75	3+12.1
31B	1+13.7	1353.2	76B	1+24.1	1351.4	76	3+32.1
32B	1+14 5	1353.1	77B	1+24.1	1351.4	77	3+52.1
33B	1+13.0	1353.6	80B	1+08.8	1354.1	78	3+72.1
34B	1+00.4	1353.5	81B	1+09.8	1354.0	79	3+92.1
35B	1+04.2	1354.1				80	4+04.5
36B	1+12 0	1353.5				81	4+05.4
37B	1+12.2	1353.7				82	4+06.5
38B	1+06.0	1361.0				83	4+07.8
39B	1+10.1	1360.3				84	4+09.6
40B	1+01.4	1369.5				85	4+11.9
41B	1+03.3	1368.4	41	1+30.9	1354.2	86	4+14.1
42B	1+05.2	1367.7	42	1+31.5	1353.1		
43B	1+08.2	1366.8	43	1+32.2	1351.9		
44B	1+10.0	1366.4	44	1+33.3	1352.7		
45B	1+08 0	1367.3	45	1+33.3	1351.7		



LONG CENTER LINE



PIEZOMETER LOCATIONS

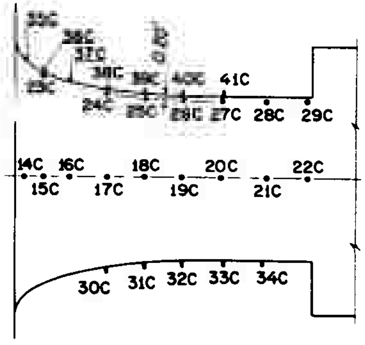
ELEV	PIEZ NO.	STATION	ELEV	PIEZ NO.	STATION	ELEV
352 1	46B	1+15.8	1353 9	46	1+33.3	1350.7
352 3	47B	1+15.8	1353.9	47	1+33.3	1349 7
352.0	48B	1+18 1	1355 5	48	1+35 0	1352 4
352 3	49B	1+18.1	1353.5	49	1+35.0	1351.4
369 1	50B	1+18 1	1355 5	50	1+35 0	1350.4
367 9	51B	1+18 1	1353 5	51	1+35.0	1349.4
367 1	52B	1+18 6	1361 4	152B	1+35 0	1348 2
366 6	53B	1+18.6	1355 4	53	1+36.5	1351.2
366 3	54B	1+18.6	1353.4	54	1+36.5	1349 2
366 1	55B	1+18 6	1352 8	55	1+38.0	1351.9
365 9	56B	1+19 6	1361 2	56	1+38.0	1349 9
370.5	57B	1+19.6	1355 2	57	1+38.0	1348 9
368 2	58B	1+19 6	1353 2	158B	1+38.0	1347.8
366 9	59B	1+19.6	1352 6	59	1+39 5	1350.6
366 5	60B	1+21 1	1360.9	60	1+39 5	1348 6
66 1	61B	1+21.1	1354 9	61	1+41 0	1351.4
65 9	62B	1+21.1	1352 9	62	1+41 0	1349 4
65 8	63B	1+21.1	1352 3	63	1+41.0	1348.4
62 1	64B	1+22 .	1354.8	64	1+42.5	1350.1
61.5	65B	1+22 1	1352 8	65	1+42.5	1348.1
60 8	66B	1+22.1	1351.8	166B	1+42.5	1347.1
60 3	67B	1+23.1	1360.6	167B	1+52 0	1345.4
30.0	68B	1+23.1	1354.6	168B	1+70.0	1341 5
69.2	69B	1+23.1	1352.6	69	1+92 1	1335.4
67 3	70B	1+23 1	1352.0	70	2+12.1	1328.3
36.5	71B	1+23.1	1354 6	71	2+32 1	1321.3
36.1	72B	1+23.1	1352.6	72	2+52 1	1312 9
36.1	73B	1+23 1	1352 0	73	2+72 1	1303.6
35 5	74B	1+24 1	1354.4	74	2+92.1	1293.4
33.4	75B	1+24.1	1352 4	75	3+12. 1	1282.3
33 2	76B	1+24 1	1351 4	76	3+32 1	1270.3
33.1	77B	1+24 1	1351 4	77	3+52.1	1257.5
3.6	80B	1+08.8	1354.1	78	3+72.1	1243.7
3 5	81B	1+09 8	1354 0	79	3+92 1	1229.1
4.1				80	4+04.5	1219.4
3.5				81	4+05 4	1218.7
3 7				82	4+06 5	1217.9
1 0				83	4+07.8	1216.8
0 3				84	4+09 6	1215.4
9.5				85	4+11.9	1213.7
8.4	41	1+30 9	1354 2	86	4+14.1	1212.0
7 7	42	1+31 5	1353 1			
6 8	43	1+32 2	1351 9			
6.4	44	1+33 3	1352 7			
7.3	45	1+33 3	1351 7			

NOTE

1. PIEZOMETERS 41 TO 51, 53 TO 57, 59 TO 65 AND 69 TO 86 ARE UNCHANGED FROM ORIGINAL DESIGN, PLATE 90.

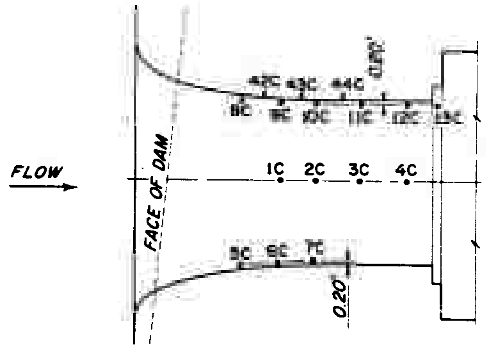
PIEZOMETER LOCATIONS

PLAN B RIGHT CONDUIT



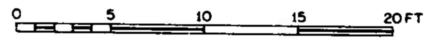
SECTION A-A

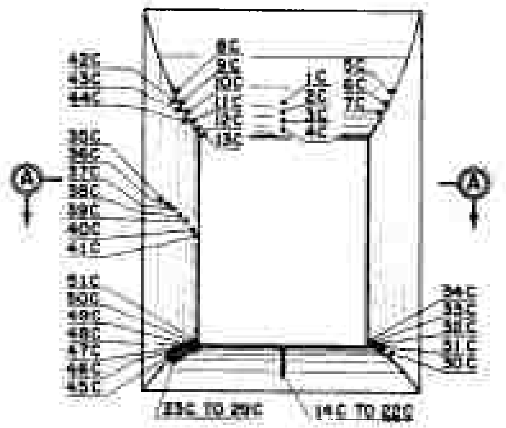
FLOW



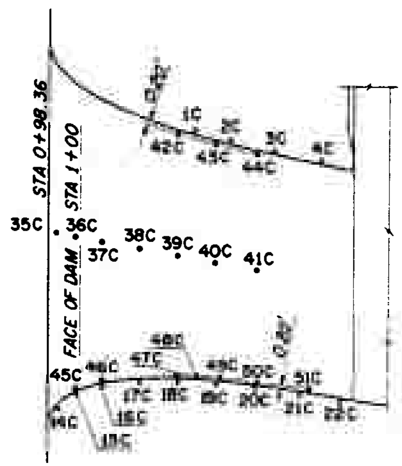
PLAN

SCALE





FACE VIEW

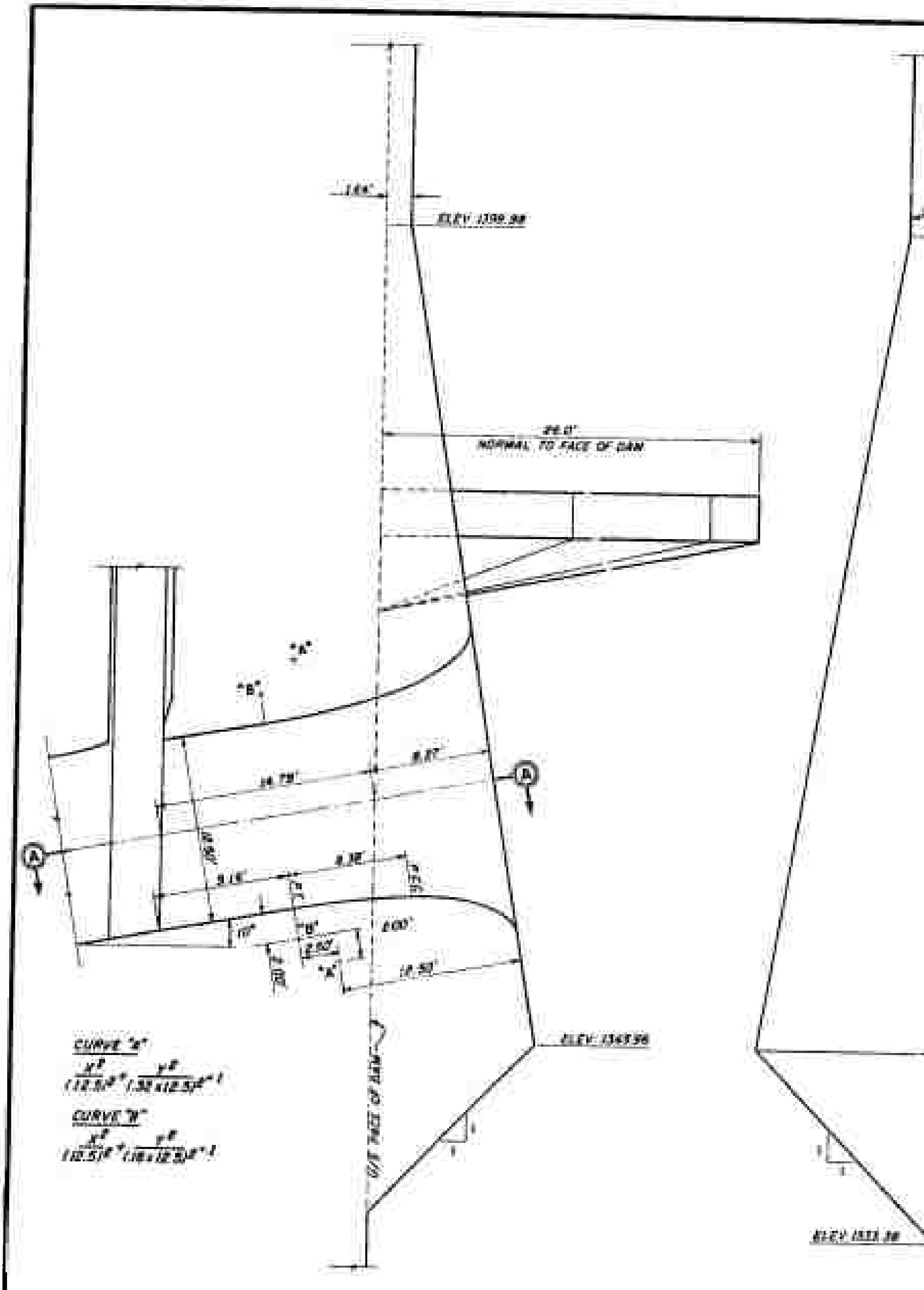


ELEVATION ALONG CENTER LINE

PIEZOMETER LOCATIONS					
PIEZ NO.	STATION	ELEV	PIEZ NO.	STATION	ELEV
1C	1+06.0	1367.6	26C	1+07.2	1354.0
2C	1+07.9	1367.1	27C	1+09.3	1353.9
3C	1+10.3	1366.6	28C	1+11.7	1353.5
4C	1+12.8	1366.1	29C	1+13.9	1353.2
5C	1+04.0	1368.2	30C	1+03.2	1354.3
6C	1+06.0	1367.6	31C	1+05.2	1354.3
7C	1+07.9	1367.1	32C	1+07.2	1354.3
8C	1+04.0	1368.2	33C	1+09.4	1354.1
9C	1+05.0	1367.6	34C	1+11.5	1353.8
10C	1+07.9	1367.1	35C	0+98.8	1362.3
11C	1+10.3	1366.6	36C	0+99.8	1362.0
12C	1+12.8	1366.1	37C	1+01.2	1361.8
13C	1+14.4	1365.8	38C	1+03.2	1361.4
14C	0+98.8	1352.6	39C	1+05.2	1361.1
15C	0+99.8	1353.5	40C	1+07.2	1360.7
16C	1+01.2	1354.0	41C	1+09.4	1360.4
17C	1+03.2	1354.1	42C	1+05.2	1367.6
18C	1+05.2	1353.2	43C	1+07.2	1367.1
19C	1+07.2	1354.1	44C	1+09.4	1366.6
20C	1+09.3	1353.9	45C	0+99.8	1352.6
21C	1+11.7	1353.6	46C	1+01.2	1354.0
22C	1+13.9	1353.2	47C	1+05.2	1354.3
23C	0+99.8	1353.3	48C	1+06.4	1354.3
24C	1+03.2	1354.2	49C	1+07.5	1354.2
25C	1+05.2	1354.1	50C	1+09.4	1354.1
			51C	1+12.2	1353.5

PIEZOMETER LOCATIONS

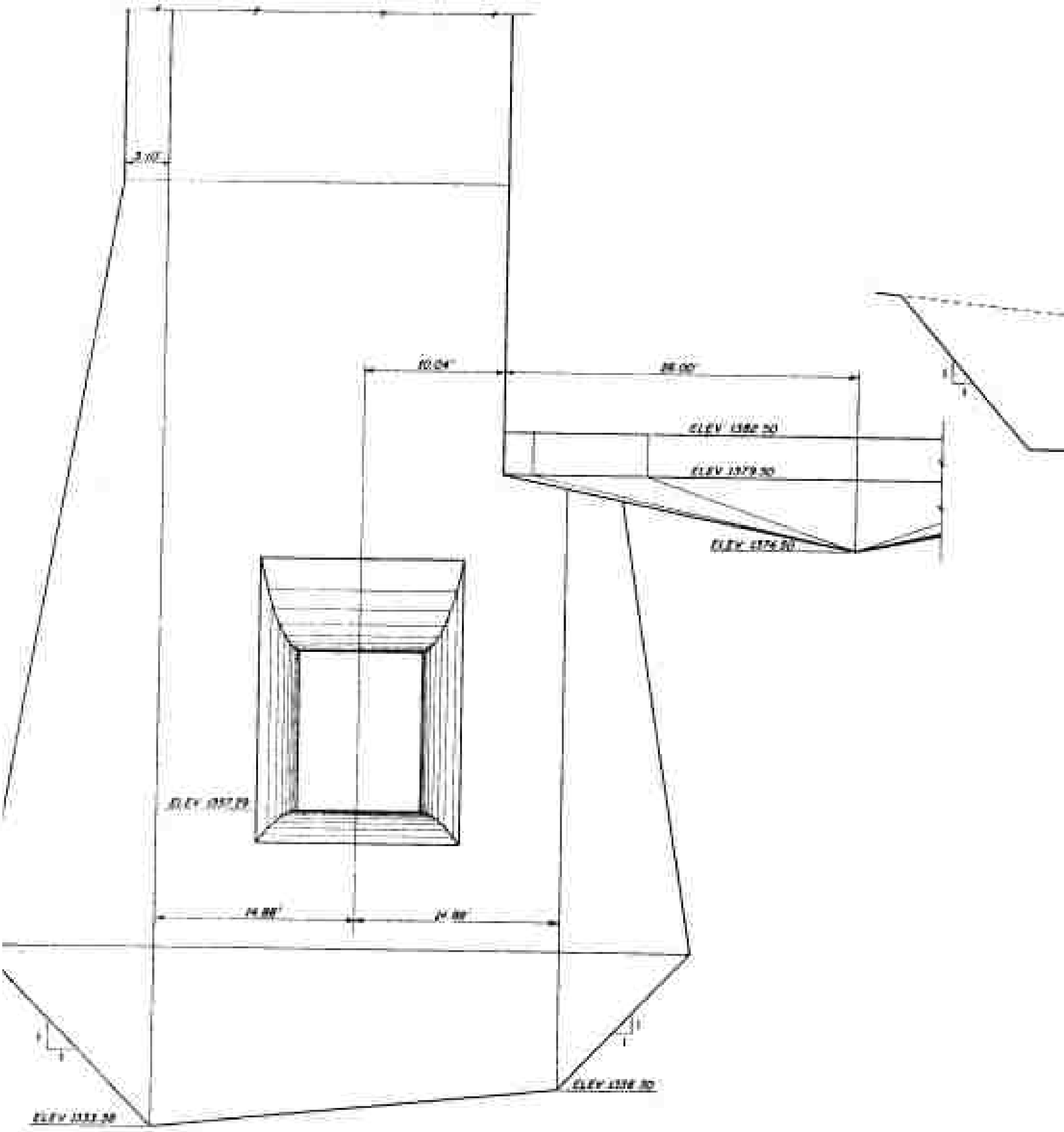
PLAN C RIGHT CONDUIT ENTRANCE



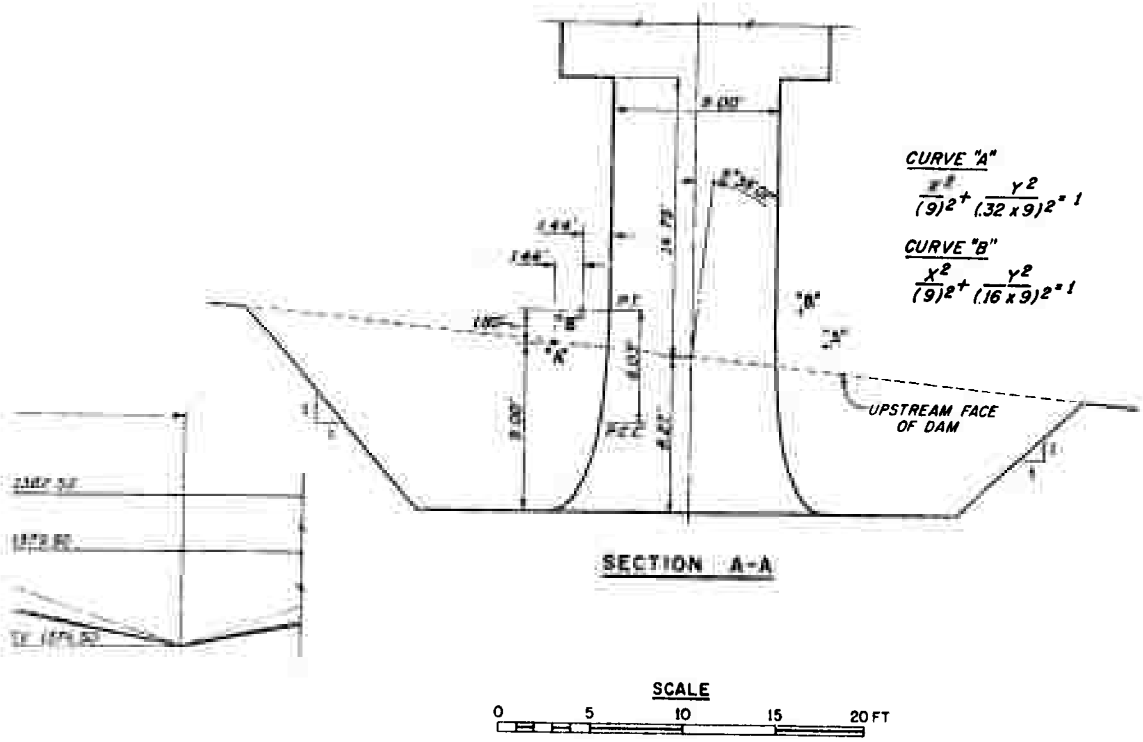
SECTION ALONG CENTER LINE

Plate 96

1



FACE VIEW OF INTAKE

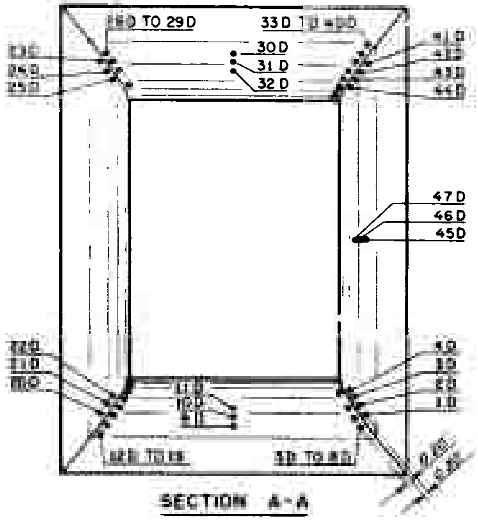


$$\text{CURVE "A"}: \frac{X^2}{(9)^2}+\frac{Y^2}{(.32 \times 9)^2}=1$$

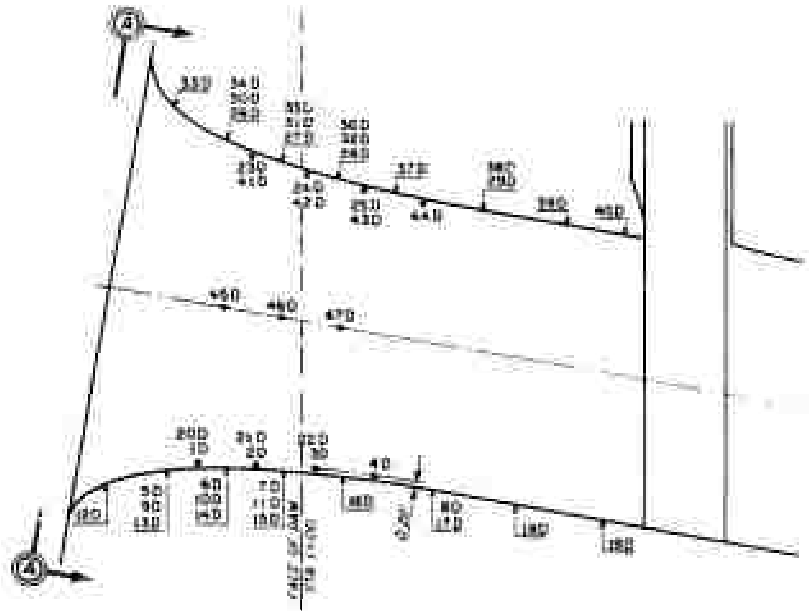
$$\text{CURVE "B"}: \frac{X^2}{(9)^2}+\frac{Y^2}{(.16 \times 9)^2}=1$$

PLAN D RIGHT CONDUIT ENTRANCE

3 of 3



SECTION A-A



SECTION ALONG CENTER LINE

SCALE

0 5 10 15 20 FT

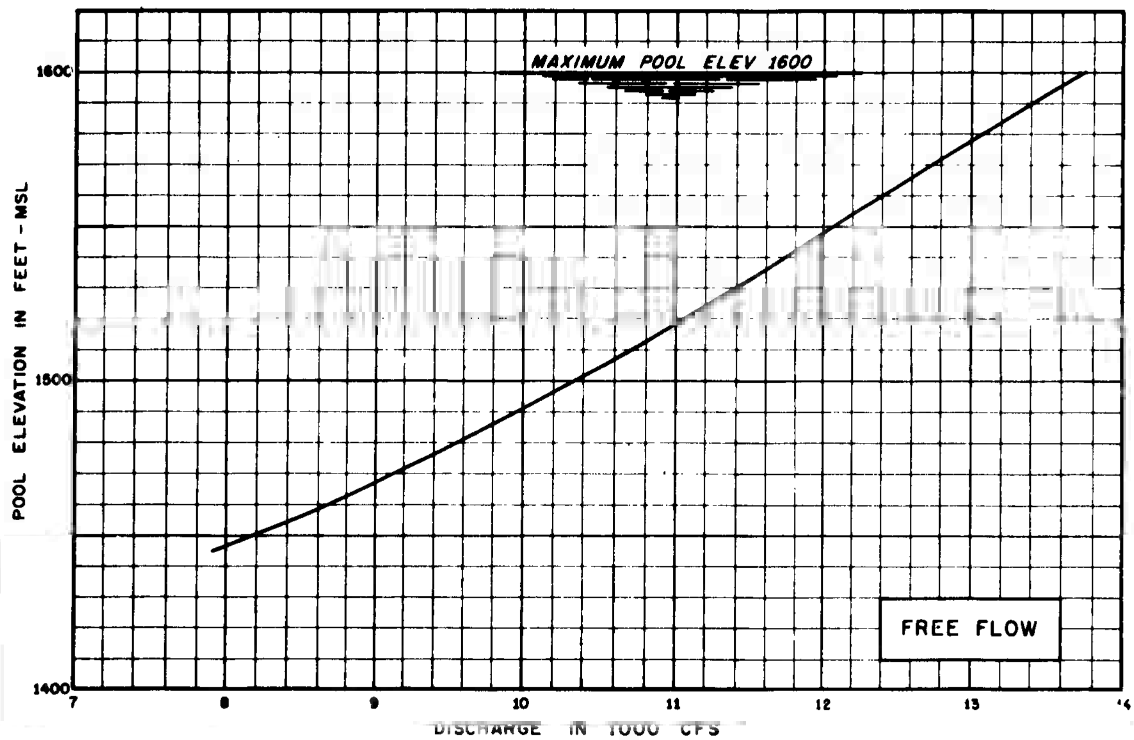
PIEZ NO	STATION	ELEVATION	PIEZ NO	STATION	ELEVATION
1D	0+95.6	1355.8	26D	0+96.8	1370.1
2D	0+98 1	1355 7	27D	0+99 1	1369 1
3D	1+00 6	1355 5	28D	1+01 6	1368.4
4D	1+03.1	1355 2	29D	1+07.7	1367.0
5D	0+94 2	1355 5	30D	0+96 8	1370.1
6D	0+96 8	1355 6	31D	0+99 1	1369 1
7D	0+99 3	1355.5	32D	1+01 6	1368.4
8D	1+05 5	1354.7	33D	0+94 5	1371 6
9D	0+94 2	1355 5	34D	0+96 8	1370 1
10D	0+96 8	1355 6	35D	0+99 1	1369 1
11D	0+99 3	1355 5	36D	1+01 6	1368 4
12D	0+91 6	1354 8	37D	1+04 0	1367 7
13D	0+94 2	1355 5	38D	1+07 7	1367 0
14D	0+96 8	1355 6	39D	1+11 4	1366 4
15D	0+99 3	1355 5	40D	1+13 9	1365 9
16D	1+01 8	1355 2	41D	0+97 9	1369 3
17D	1+05 5	1354 7	42D	1+00 3	1368 5
18D	1+09 3	1354 0	43D	1+02 7	1367 8
19D	1+12 9	1353 4	44D	1+05 2	1367 3
20D	0+95 6	1355 8	45D	0+96 7	1362 6
21D	0+98 1	1355 7	46D	1+99 2	1362 1
22D	1+00 6	1355 5	47D	1+01 7	1361 7
23D	0+97 9	1369 3			
24D	1+00 3	1368 5			
25D	1+02 7	1367 8			

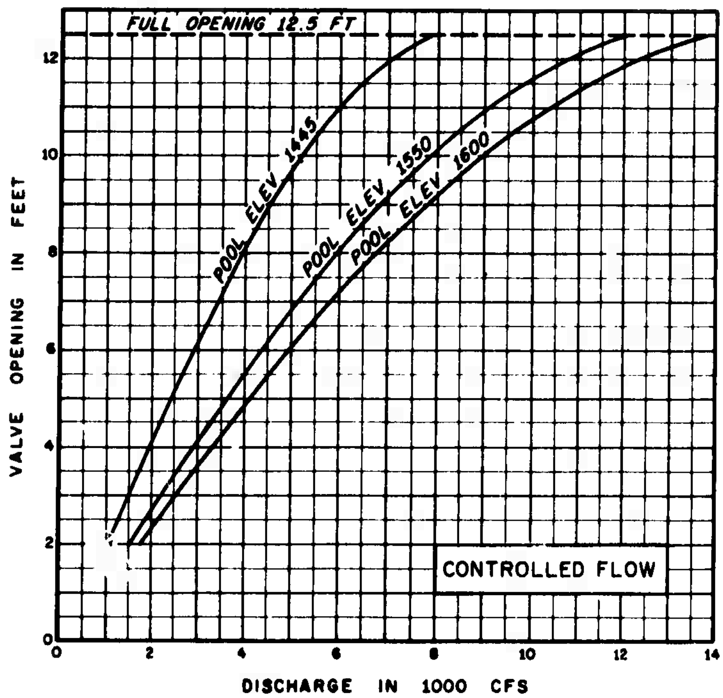
NOTE

DETAILS OF ENTRANCE ARE SHOWN ON PLATE 96

PIEZOMETER LOCATIONS

PLAN D RIGHT CONDUIT ENTR`NCE

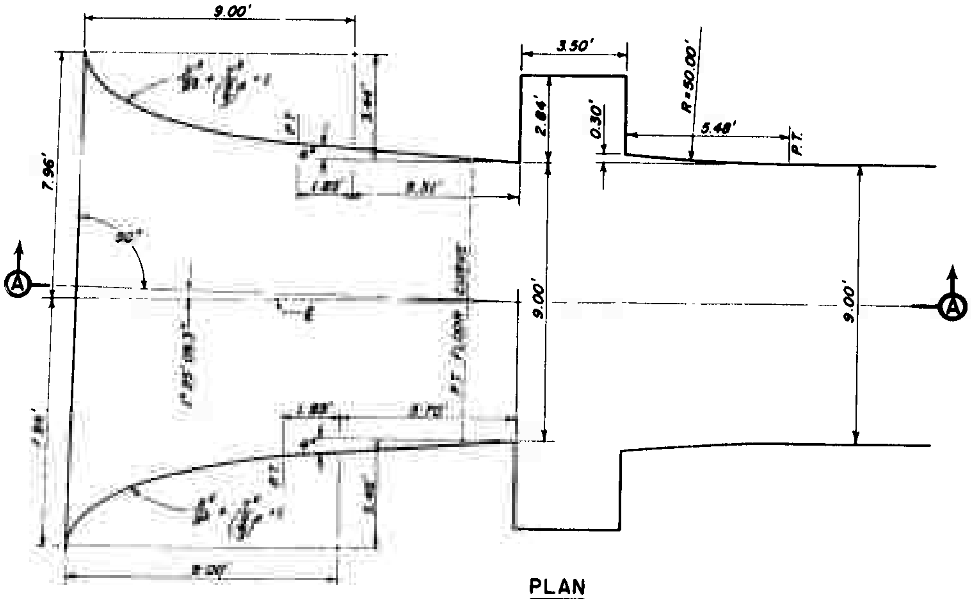




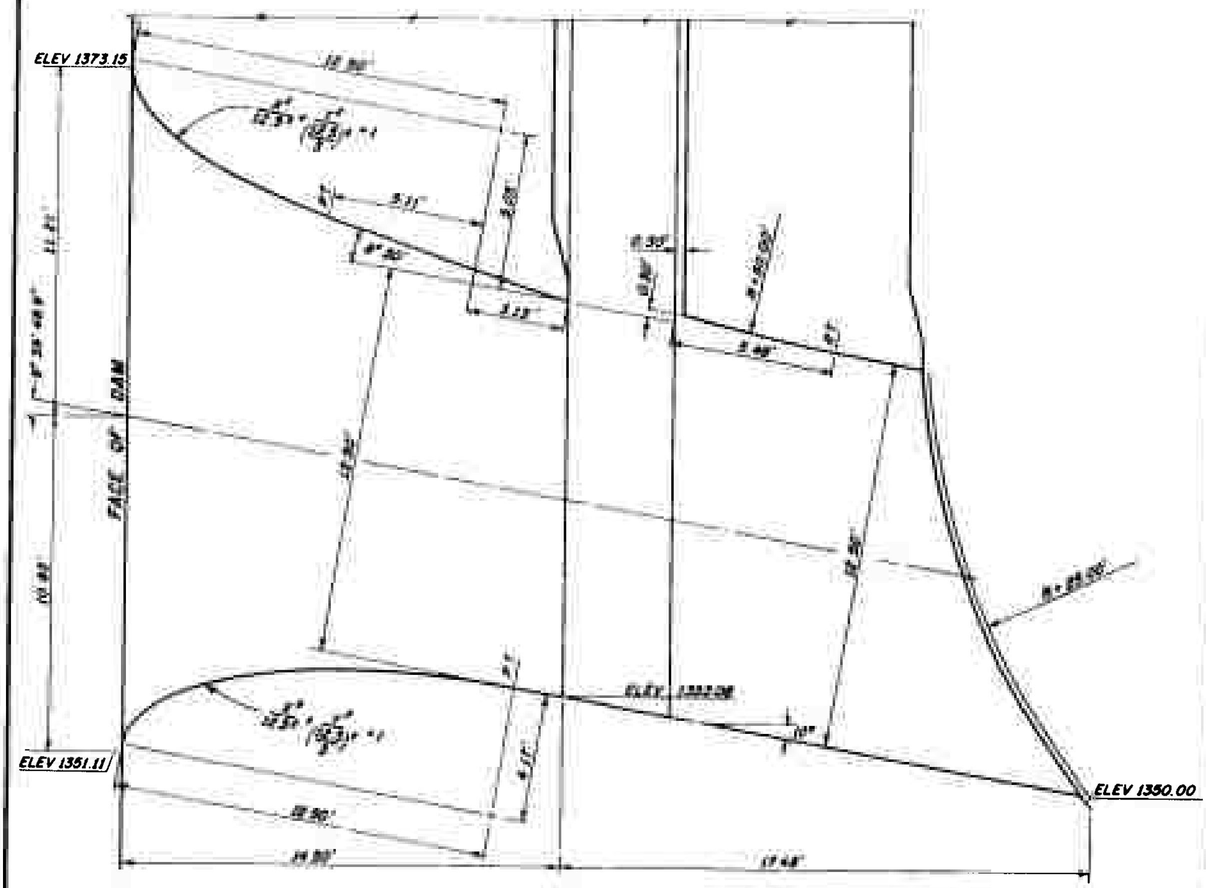
NOTE

DETAILS OF CONDUIT AND BELLMOUTH SHOWN ON PLATES 87, 89, AND 96.

DISCHARGE RATINGS
PLAN B RIGHT CONDUIT
PLAN D ENTRANCE

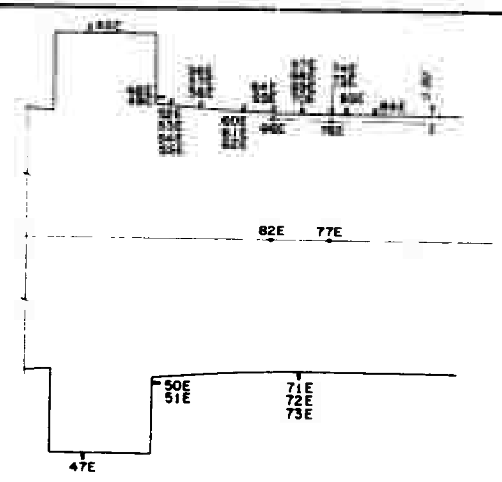


PLAN

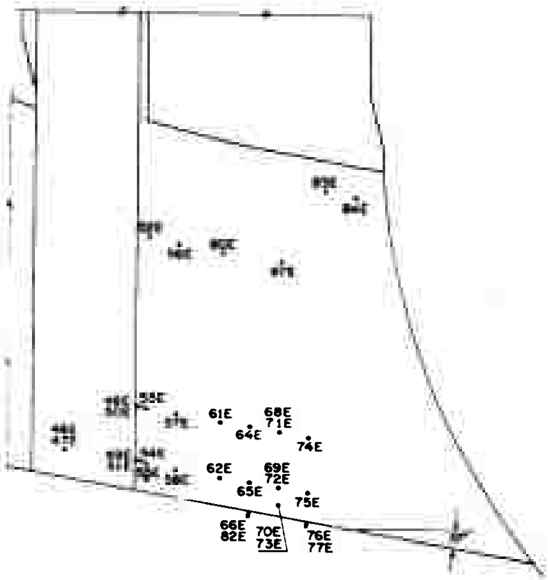


SECTION A-A

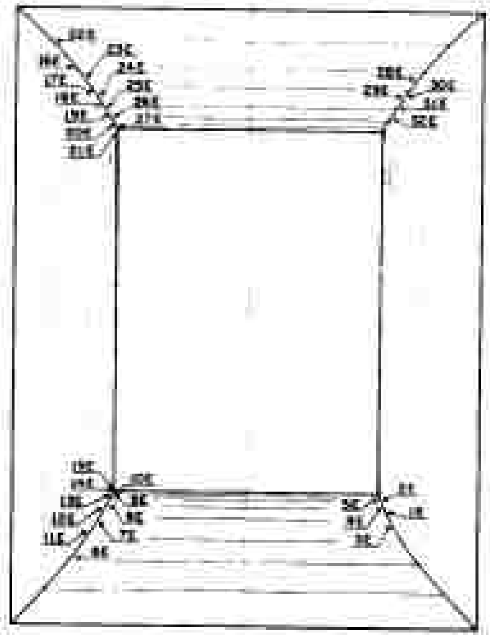
PLAN E RIGHT CONDUIT ENTRANCE



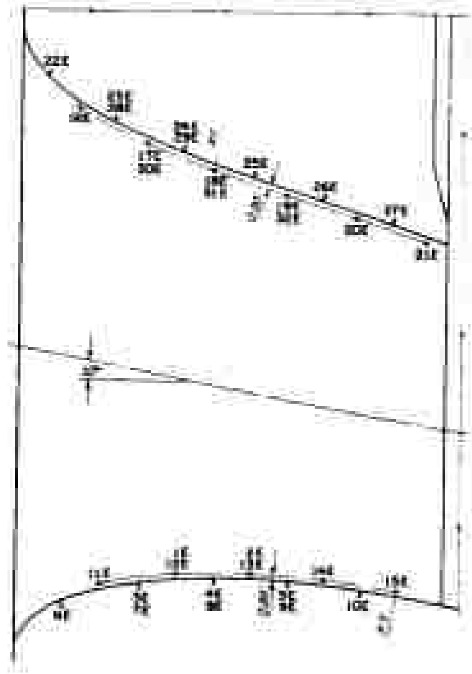
PLAN



ELEVATION



FACE VIEW NORMAL TO CENTER LINE



SECTION ALONG CENTER LINE

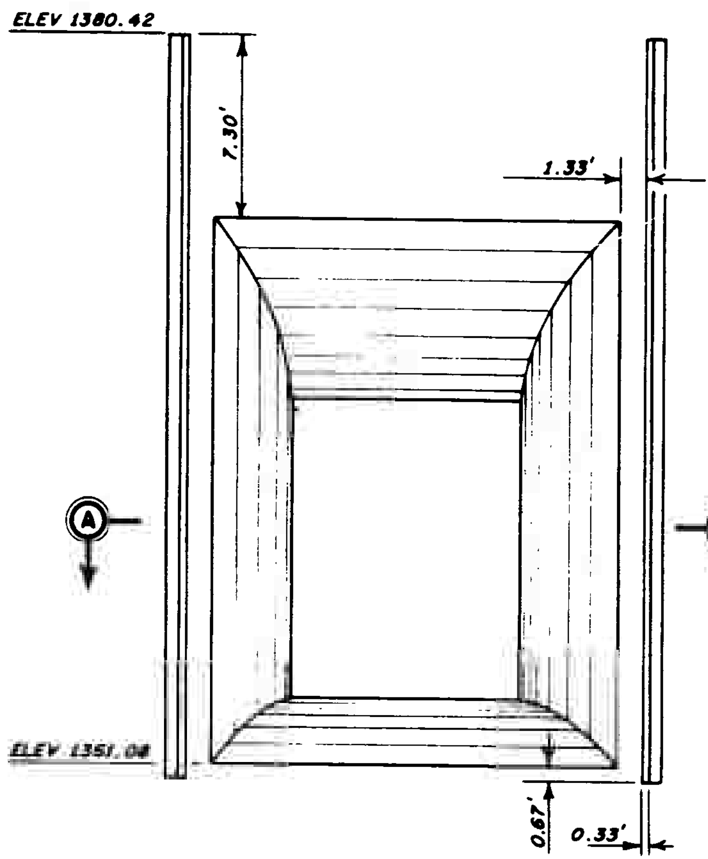
PIEZOMETER LOCATIONS											
PIEZO NO.	STATION	ELEV	PIEZO NO.	STATION	ELEV	PIEZO NO.	STATION	ELEV	PIEZO NO	STATION	ELEV
1E	1+05.4	1354.1	18E	1+06.9	1368.3	48E	1+18.0	1355.5	67E	1+23.0	1360.6
2E	1+08.0	1354.1	19E	1+09.3	1367.4	49E	1+18.0	1353.5	68E	1+23.0	1354.6
3E	1+04.1	1353.7	20E	1+11.7	1366.6	50E	1+18.0	1355.5	69E	1+23.0	1352.6
4E	1+06.7	1353.9	21E	1+14.1	1365.8	51E	1+18.0	1353.5	70E	1+23.0	1352.0
5E	1+09.2	1353.8	22E	1+01.1	1371.6	52E	1+18.5	1361.4	71E	1+23.0	1354.6
6E	1+01.7	1353.0	23E	1+03.3	1369.9	53E	1+18.5	1355.4	72E	1+23.0	1352.6
7E	1+04.3	1353.7	24E	1+05.7	1368.9	54E	1+18.5	1353.4	73E	1+23.0	1352.0
8E	1+06.9	1353.9	25E	1+08.1	1368.0	55E	1+18.5	1352.8	74E	1+24.0	1354.4
9E	1+09.4	1353.8	26E	1+10.4	1367.2	56E	1+19.5	1361.2	75E	1+24.0	1352.4
10E	1+11.9	1353.5	27E	1+12.9	1366.4	57E	1+19.5	1355.2	76E	1+24.0	1351.4
11E	1+10.3	1353.7	28E	1+03.1	1369.9	58E	1+19.5	1353.2	77E	1+24.0	1351.4
12E	1+05.6	1354.1	29E	1+05.4	1368.9	60E	1+21.0	1360.9	80E	1+08.7	1354.1
13E	1+08.2	1354.1	30E	1+14.2	1369.3	61E	1+21.0	1354.9	81E	1+09.7	1354.0
14E	1+10.7	1353.9	31E	1+06.6	1368.3	62E	1+21.0	1352.9	82E	1+22.0	1351.8
15E	1+13.2	1353.5	32E	1+09.0	1367.4	64E	1+22.0	1354.8	83E	1+24.4	1363.0
16E	1+02.2	1370.4	46E	1+15.7	1353.9	65E	1+22.0	1352.8	84E	1+25.4	1362.8
17E	1+04.5	1369.3	47E	1+15.7	1353.9	66E	1+22.0	1351.8			

NOTE

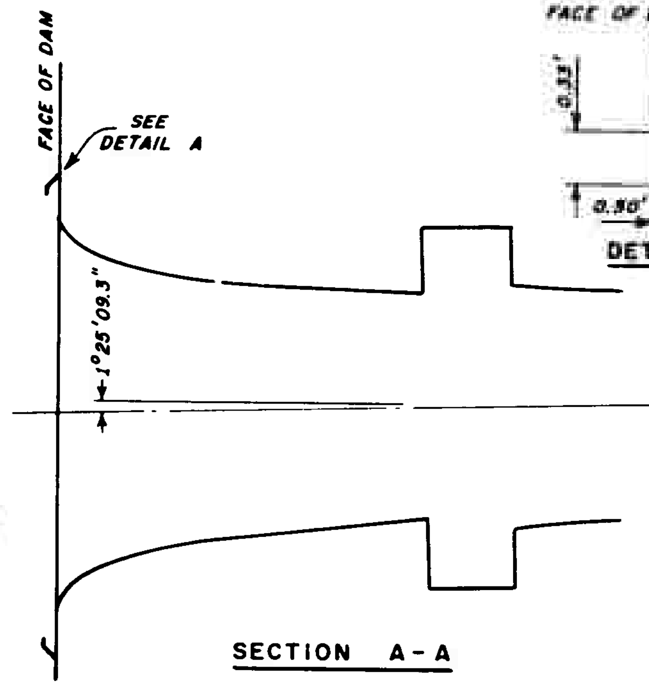
DETAILS OF ENTRANCE ARE SHOWN ON PLATE 99

PIEZOMETER LOCATIONS

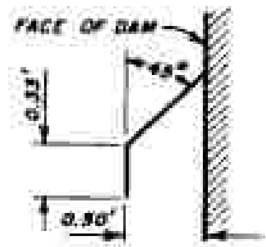
PLAN E RIGHT CONDUIT ENTRANCE



FACE VIEW



SECTION A-A



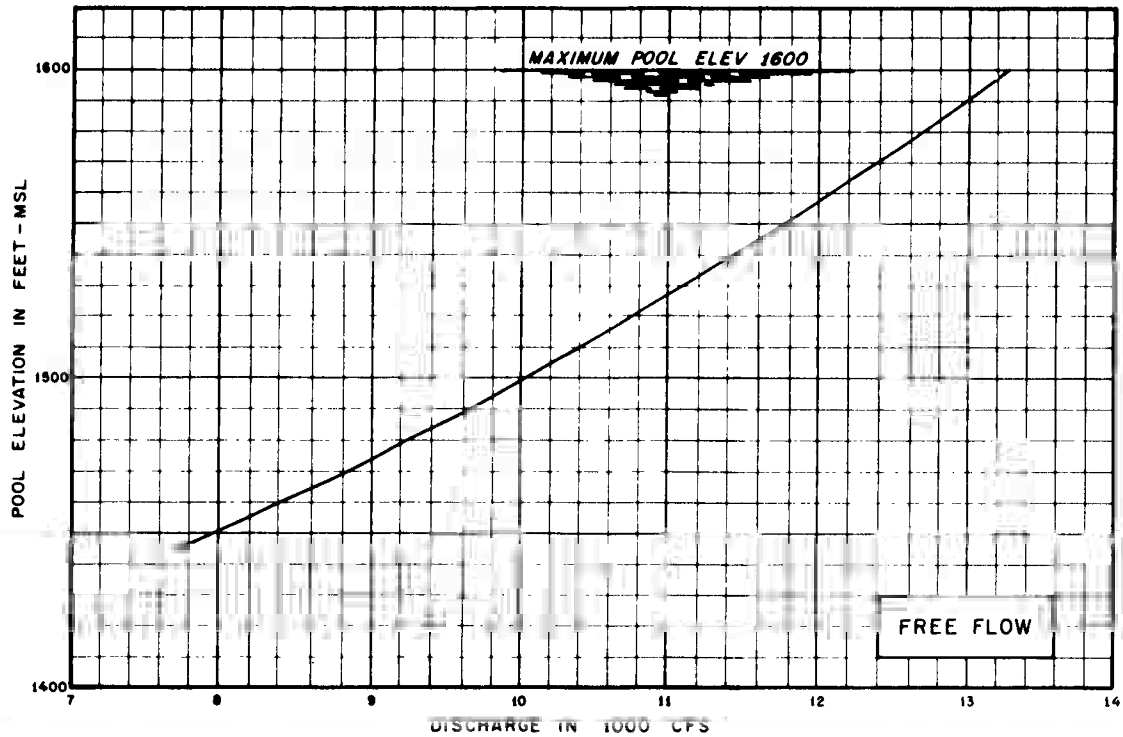
DETAIL A

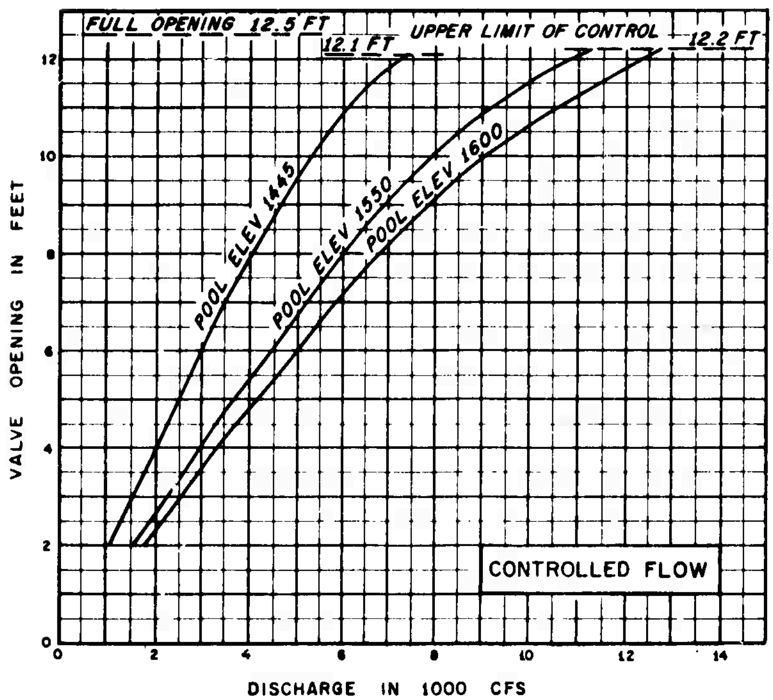
NOTES

1. BELLMOUTH DETAILS SHOWN ON PLATE 99.
2. TOP OF PROTOTYPE GUIDES AT ELEV 1529.5.

BULKHEAD GUIDES

PLAN E RIGHT CONDUIT ENTRANCE





NOTE

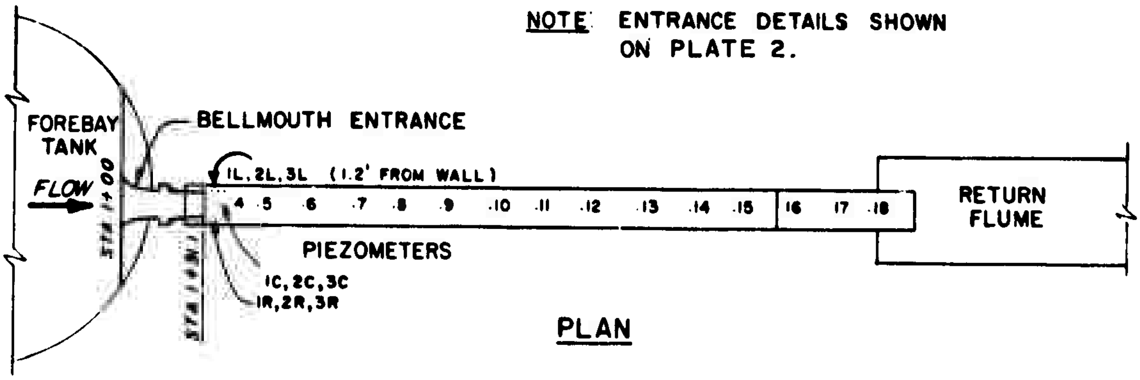
DETAILS OF CONDUIT AND BELLMOUTH SHOWN ON PLATES 87, 89, AND 99.

DISCHARGE RATINGS

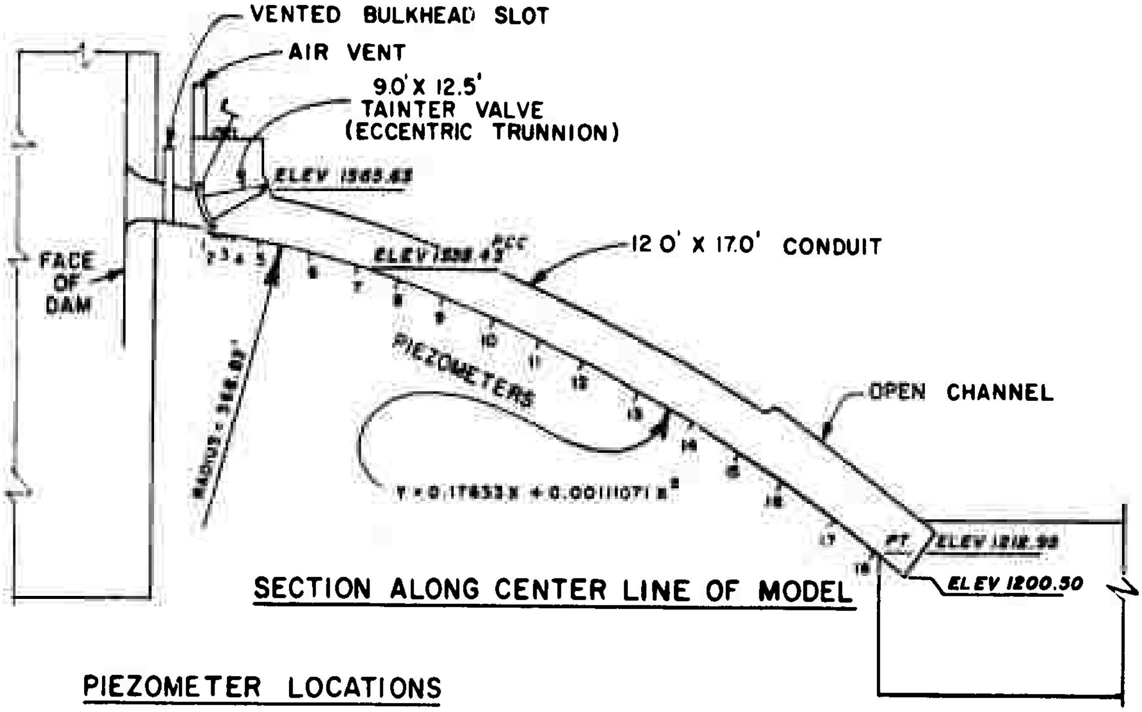
PLAN B RIGHT CONDUIT

PLAN E ENTRANCE

NOTE: ENTRANCE DETAILS SHOWN ON PLATE 2.



PLAN

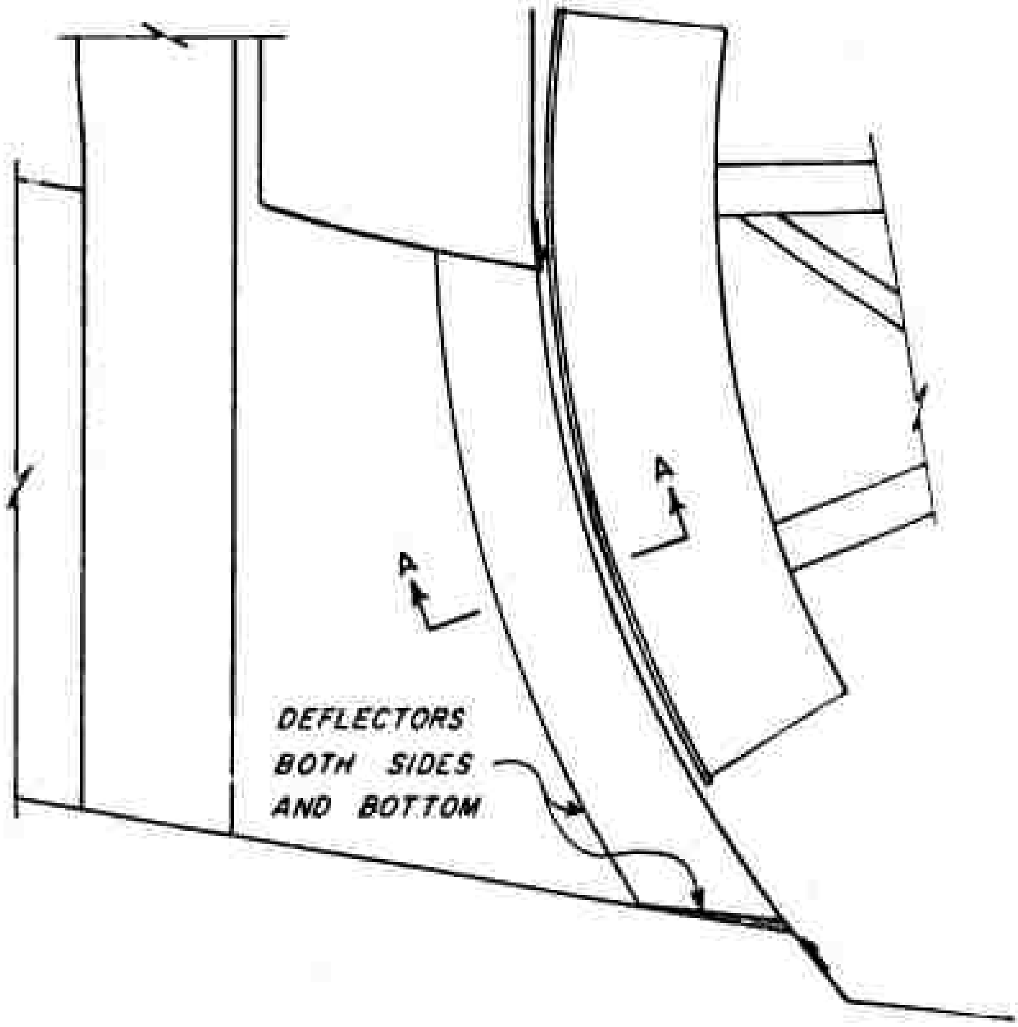


SECTION ALONG CENTER LINE OF MODEL

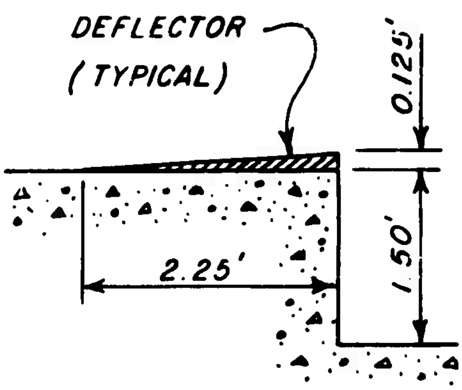
PIEZOMETER LOCATIONS

NO.	STATION	ELEVATION
1	1 + 32.1	1348.4
2	1 + 34.1	1348.1
3	1 + 36.1	1347.8
4	1 + 40.1	1347.2
5	1 + 50.1	1345.4
6	1 + 70.1	1341.0
7	1 + 88.1	1336.0
8	2 + 07.5	1329.7
9	2 + 28.4	1321.9
10	2 + 48.9	1318.4
11	2 + 68.6	1304.3
12	2 + 87.8	1294.6
13	3 + 11.9	1281.2
14	3 + 31.9	1269.2
15	3 + 50.1	1257.4
16	3 + 70.1	1243.7
17	3 + 90.3	1228.9
18	4 + 10.3	1213.4

MODEL LAYOUT AND PIEZOMETER LOCATION AS-BUILT RIGHT CONDUIT

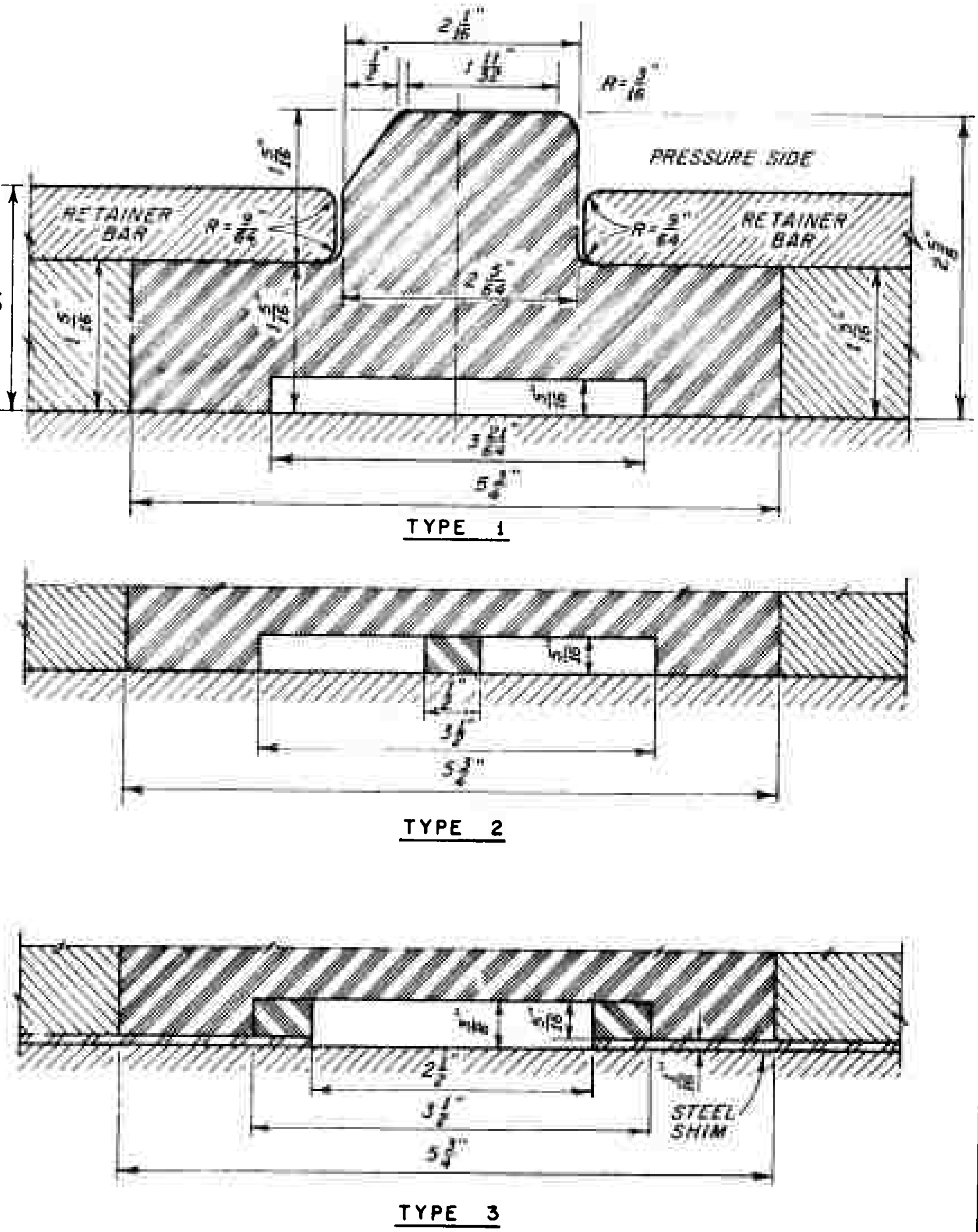


SECTION THROUGH VALVE SECTION



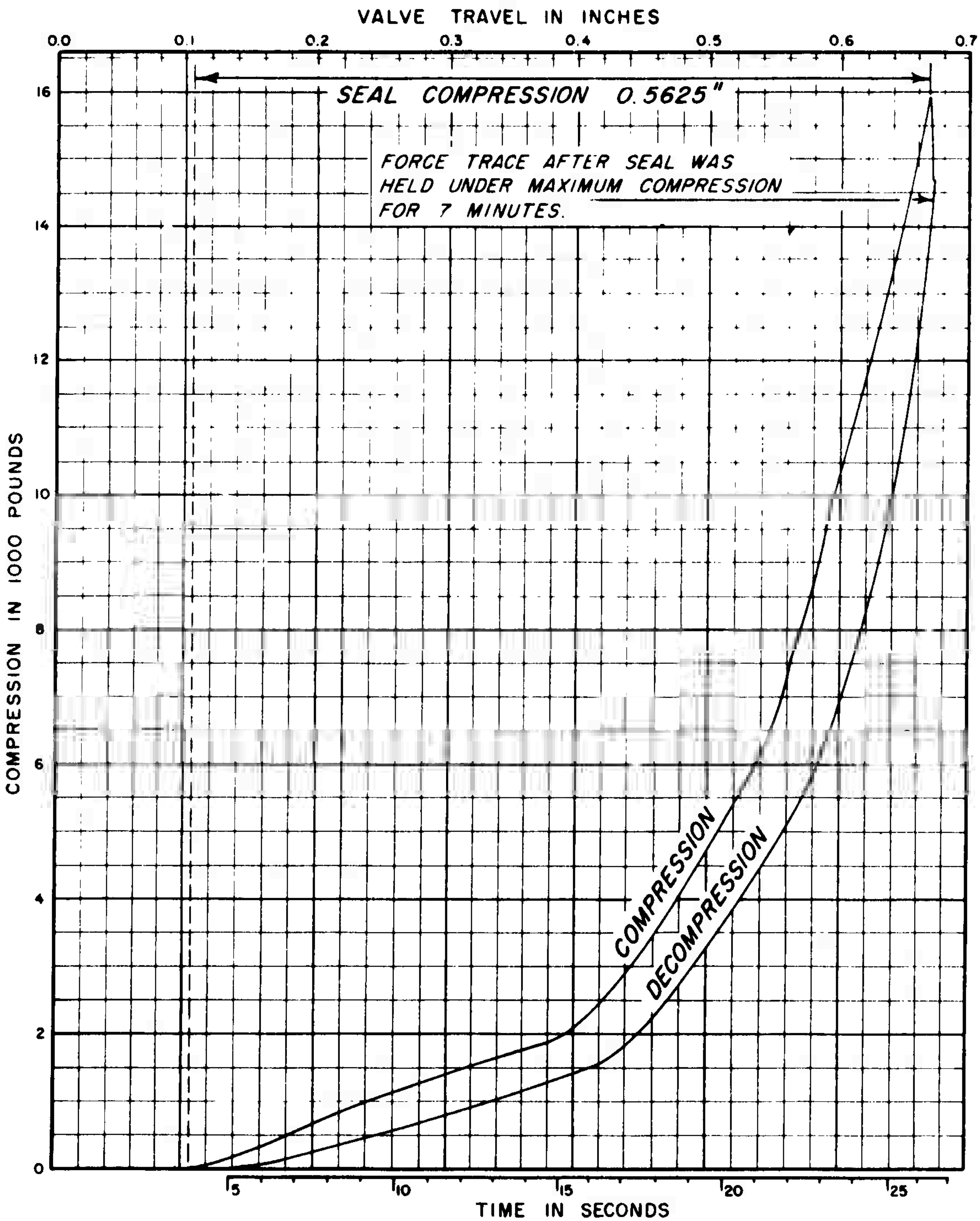
SECTION A-A

AERATION DEFLECTOR



CONDUIT TAINTER VALVE

COMPRESSION SEAL TYPES 1 TO 3



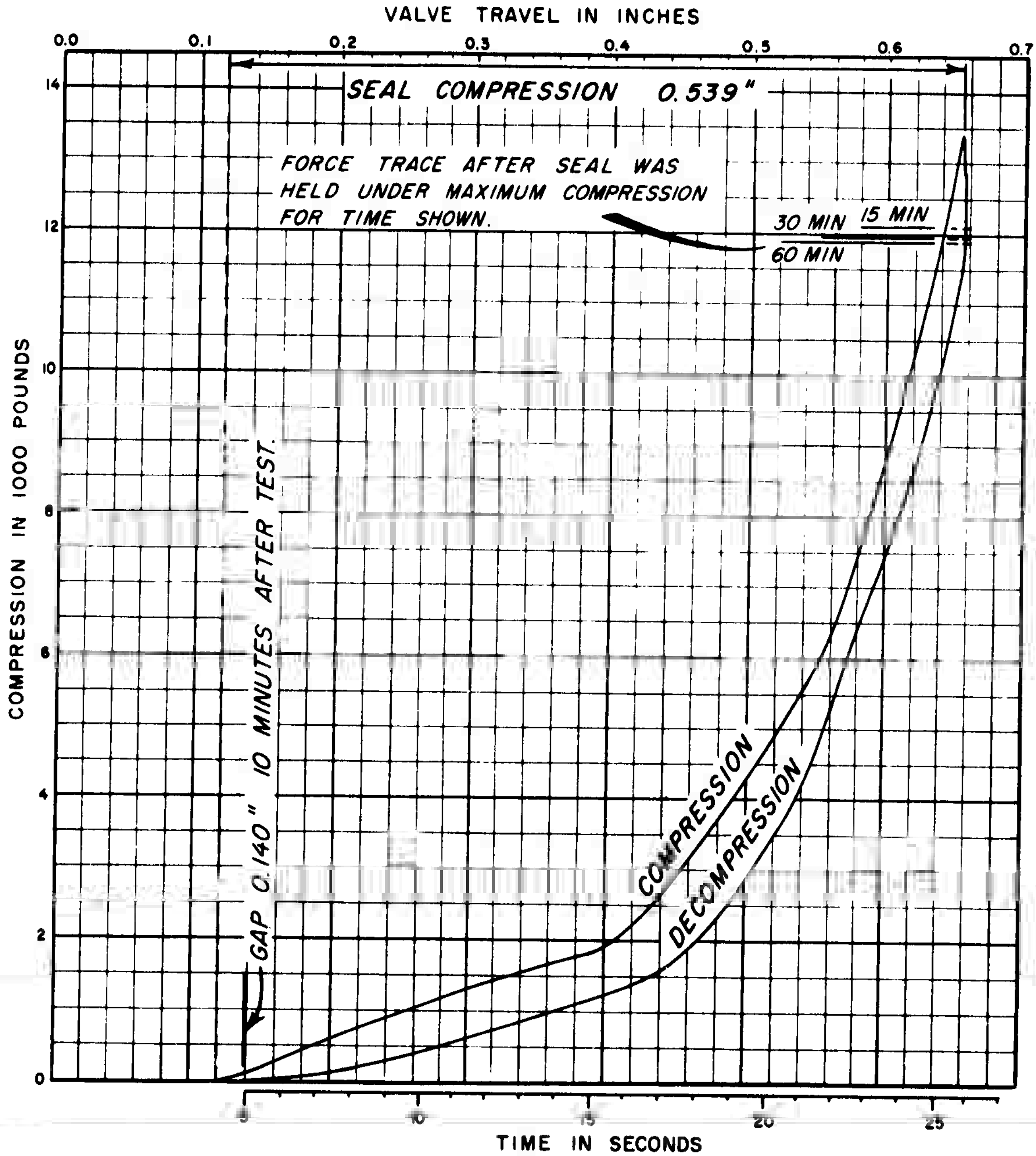
NOTES

1. SEAL LENGTH 3 FT.
2. TIME UNDER 5 SEC. WAS NONLINEAR.

FORCE TRACES

RUN 1

TYPE 1 CONDUIT TAINTER VALVE SEALS



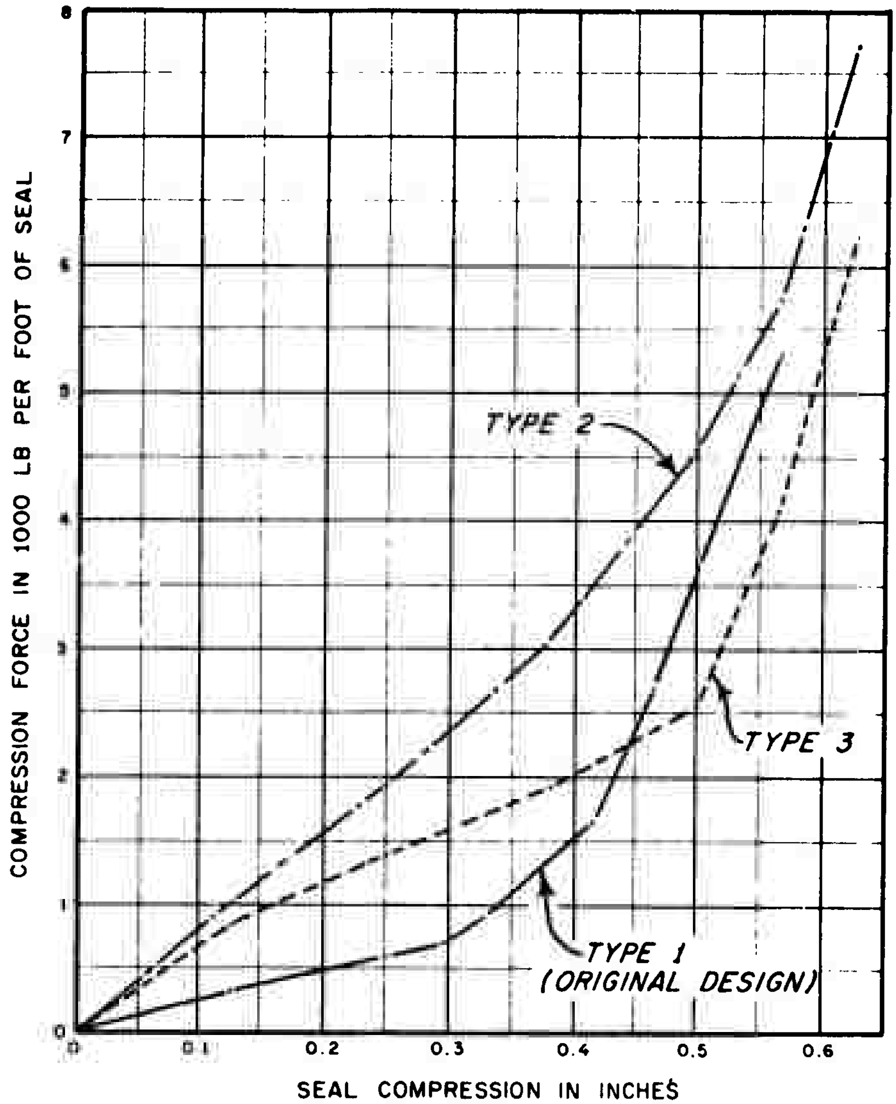
NOTES

1. SEAL LENGTH 3 FT.
2. TIME UNDER 5 SEC. WAS NONLINEAR.

FORCE TRACES

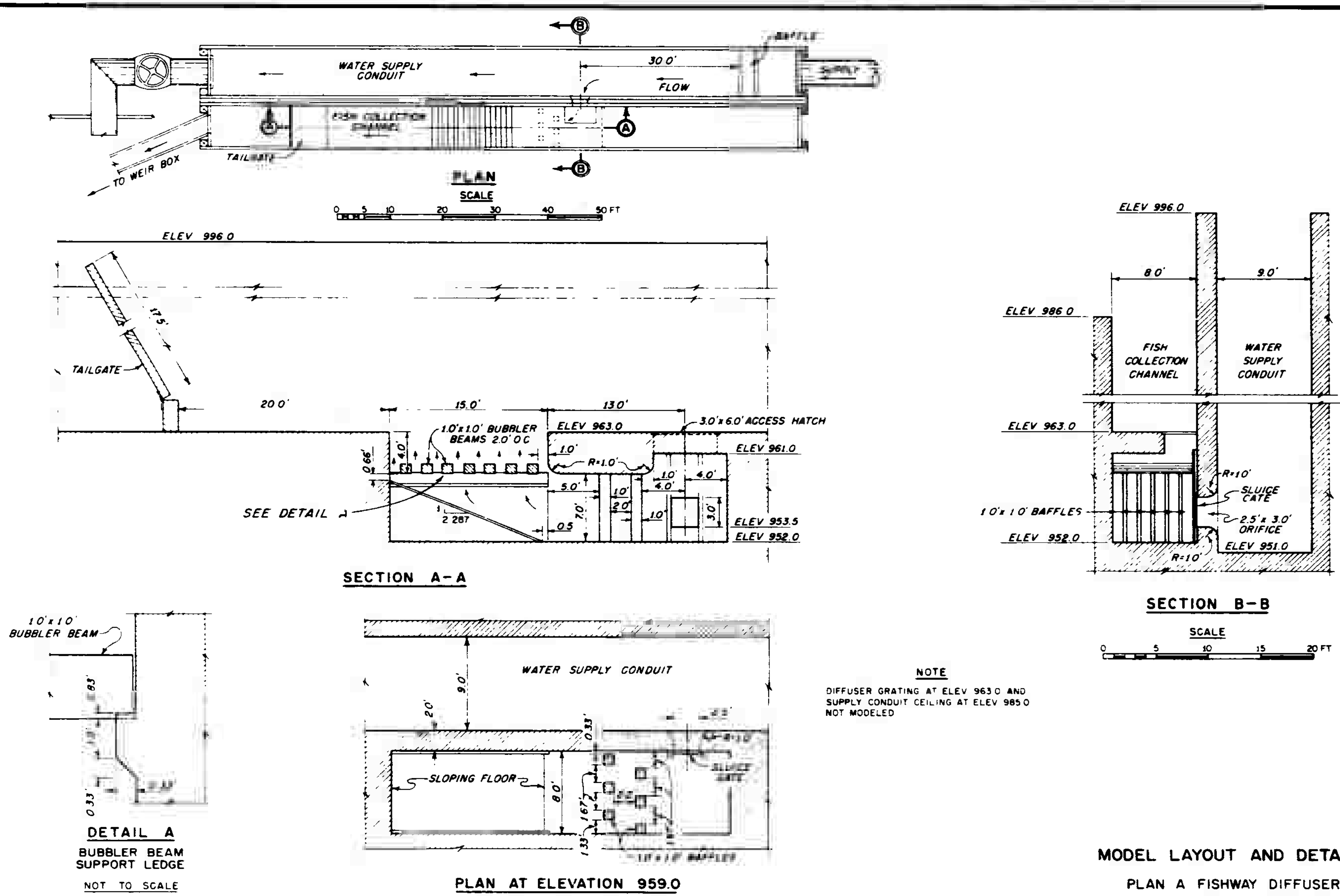
RUN 7

TYPE 1 CONDUIT TAINTER VALVE SEALS



MAXIMUM COMPRESSION FORCES

TYPES 1 TO 3 CONDUIT TAINTER VALVE SEALS

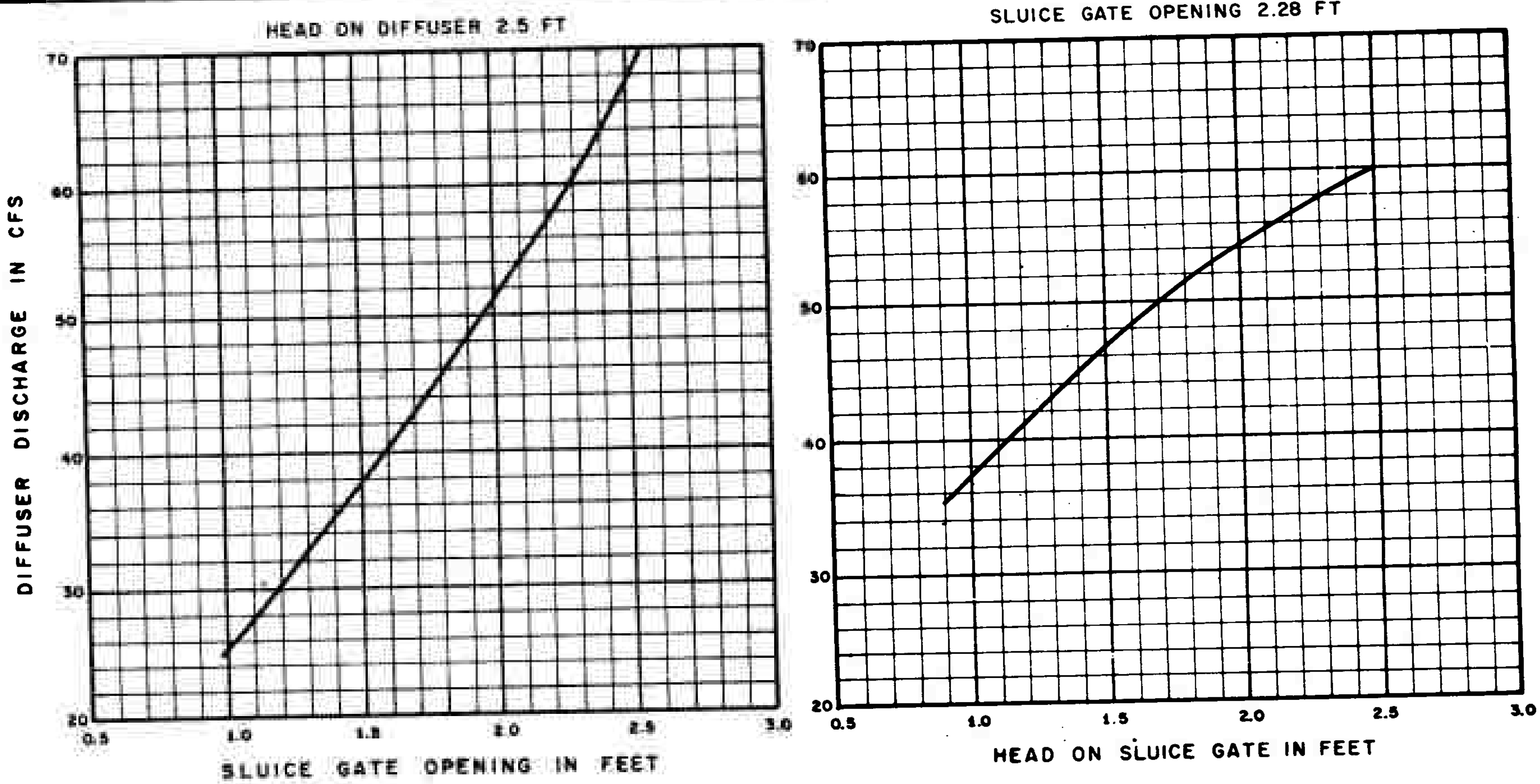


NOTE

DIFFUSER GRATING AT ELEV 963.0 AND SUPPLY CONDUIT CEILING AT ELEV 985.0 NOT MODELED

MODEL LAYOUT AND DETAILS

PLAN A FISHWAY DIFFUSER
ORIGINAL DESIGN

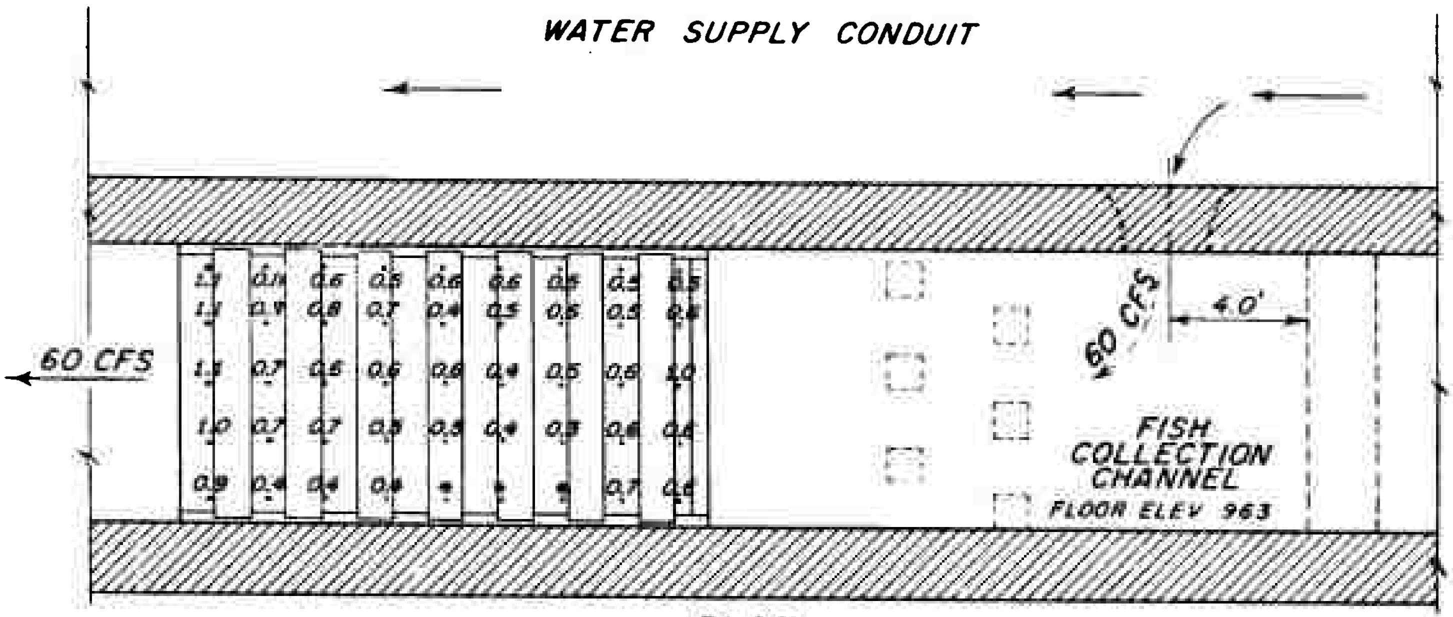


NOTES

1. DIFFUSER DETAILS SHOWN ON PLATE 109.
2. HEAD IS DIFFERENCE BETWEEN WATER SUPPLY CONDUIT HYDRAULIC GRADE LINE AND COLLECTION CHANNEL WATER SURFACE.

DISCHARGE RATINGS

PLAN A FISHWAY DIFFUSER



PLAN

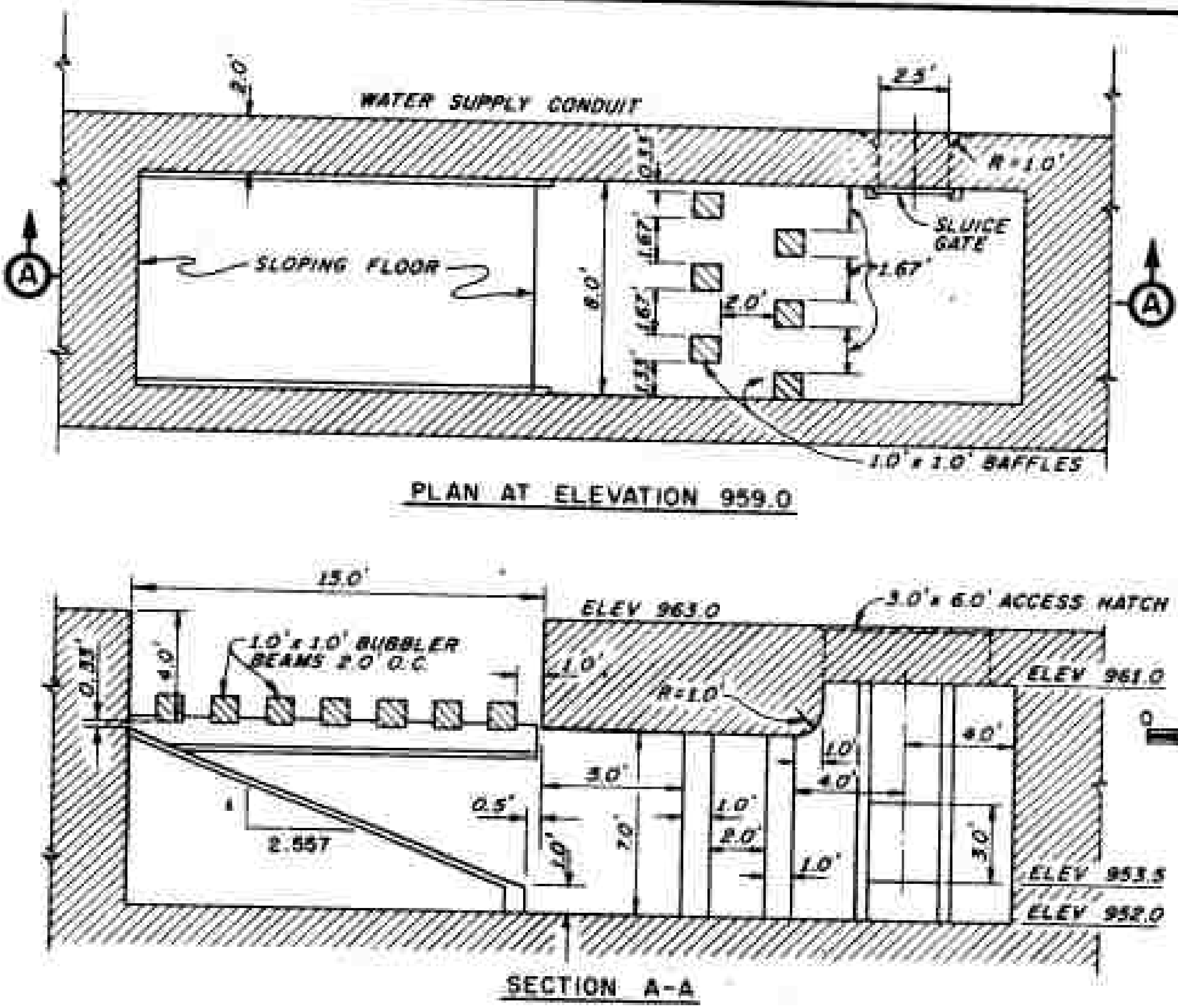
NOTES

1. VELOCITIES SHOWN IN FPS. POSITIVE VALUES INDICATE UPWARD FLOW.
2. HEAD BETWEEN SUPPLY CONDUIT AND COLLECTION CHANNEL 2.5 FT.
3. WATER SURFACE IN COLLECTION CHANNEL 1 FT ABOVE TAILWATER.
4. ONLY DIFFUSER FLOW IN COLLECTION CHANNEL.
5. TAILWATER REPRESENTS RIVER DISCHARGE OF APPROXIMATELY 12 000 CFS.
6. DIFFUSER DETAILS SHOWN ON PLATE 109.

* VELOCITY <0.3 FPS. UNSTABLE FLOW DIRECTION.

VELOCITIES AT ELEV 963

PLAN A FISHWAY DIFFUSER
POWERHOUSE TAILWATER ELEV 978



NOTE

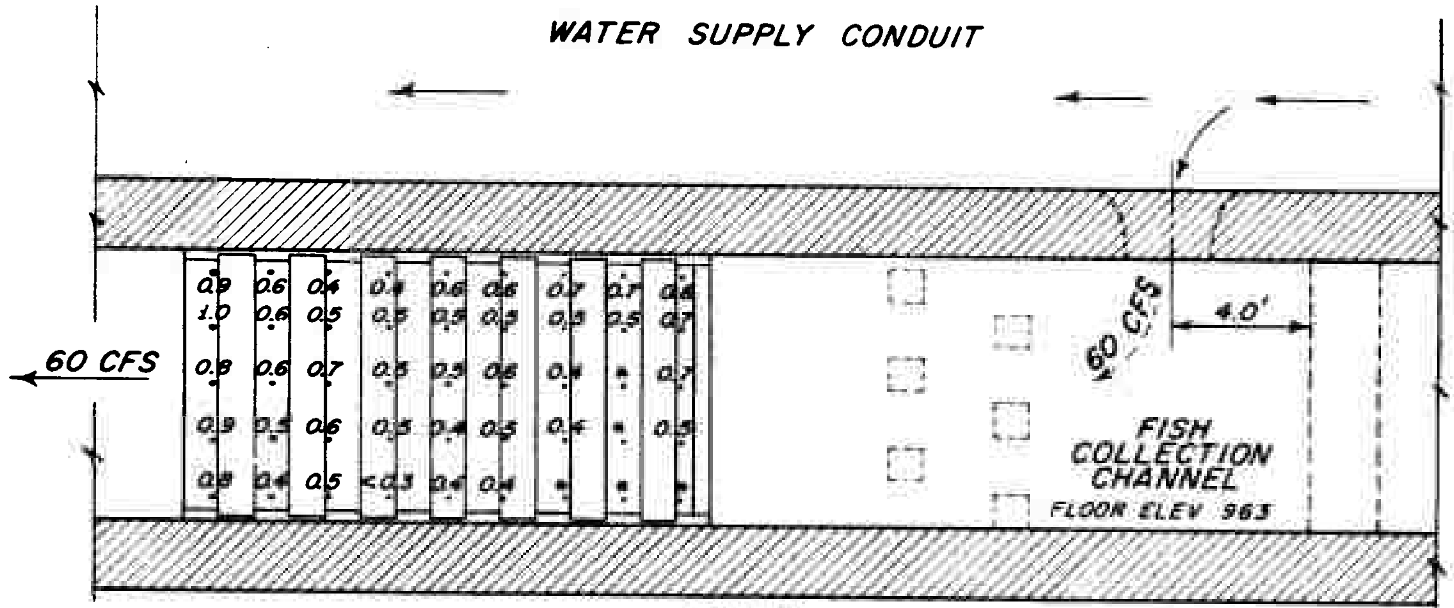
OTHER MODEL DETAILS SHOWN ON PLATE 109.

SCALE

0 5 10 15 FT

DETAILS

PLAN D-1 FISHWAY DIFFUSER
(RECOMMENDED DESIGN)



PLAN

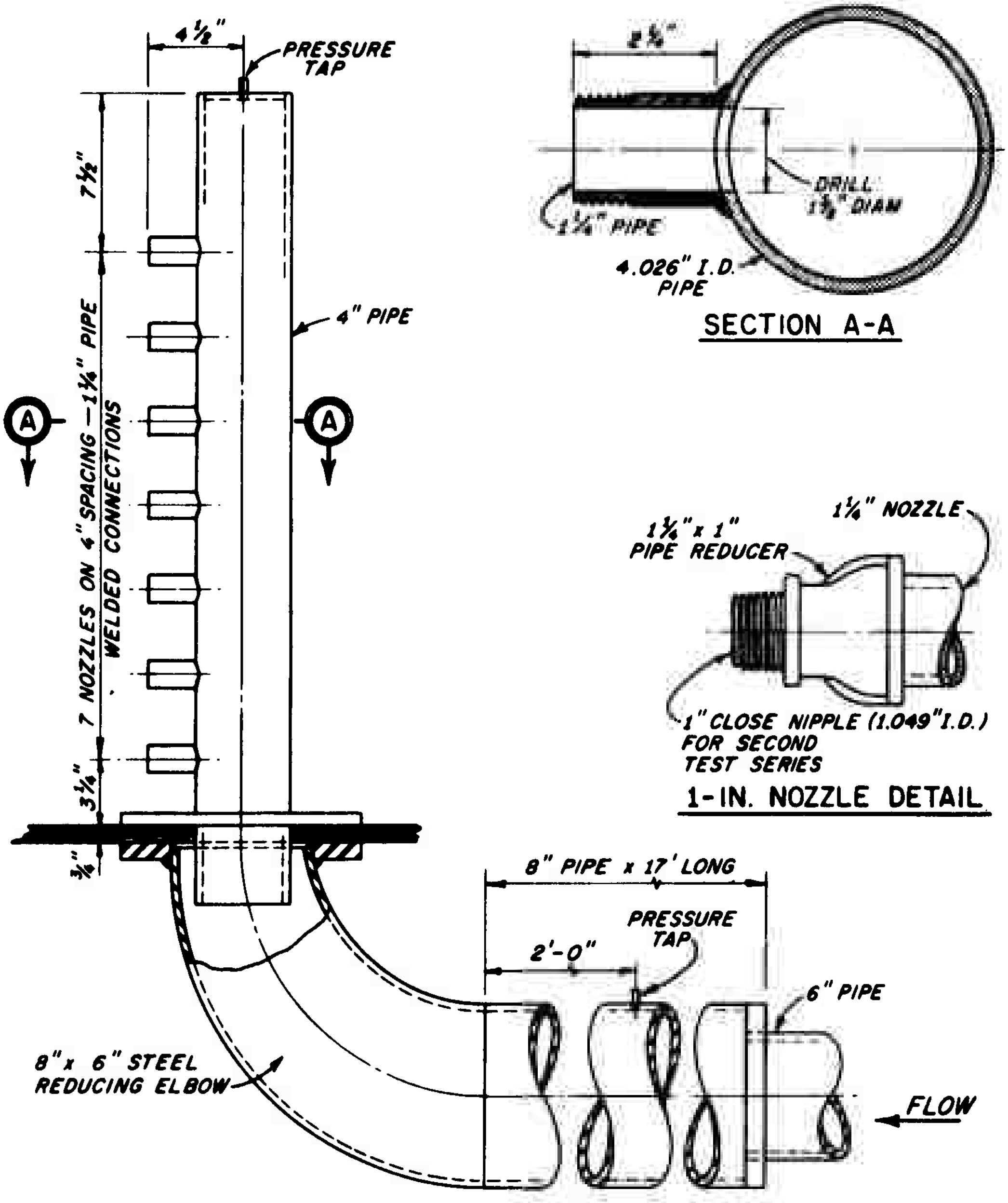
NOTES

1. VELOCITIES SHOWN IN FPS POSITIVE VALUES INDICATE UPWARD FLOW.
2. HEAD BETWEEN SUPPLY CONDUIT AND COLLECTION CHANNEL 2.5 FT.
3. WATER SURFACE IN COLLECTION CHANNEL 1 FT ABOVE TAILWATER.
4. ONLY DIFFUSER FLOW IN COLLECTION CHANNEL.
5. TAILWATER REPRESENTS RIVER DISCHARGE OF APPROXIMATELY 12 000 CFS.
6. DIFFUSER DETAILS SHOWN ON PLATE 112.

* VELOCITY <0.3 FPS. UNSTABLE FLOW DIRECTION.

VELOCITIES AT ELEV 963

PLAN D-1 FISHWAY DIFFUSER
POWERHOUSE TAILWATER ELEV 978



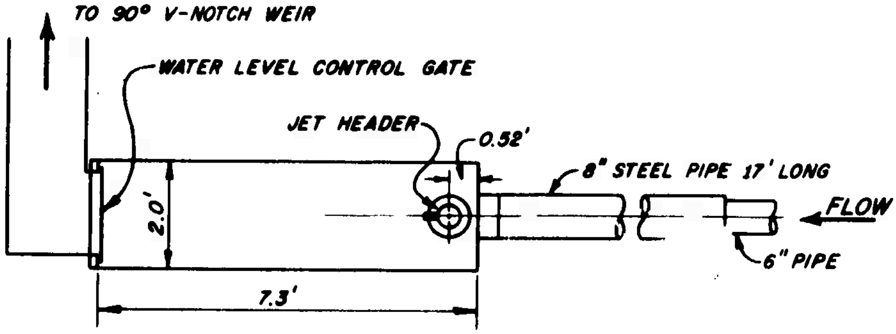
NOTE

HEADER PIPE AND NOZZLES ARE SCHEDULE 40 ALUMINUM.

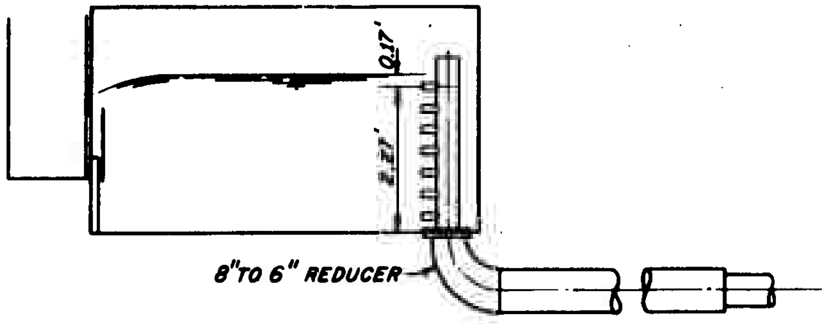
DETAILS

HATCHERY JET HEADER

PLATE 114



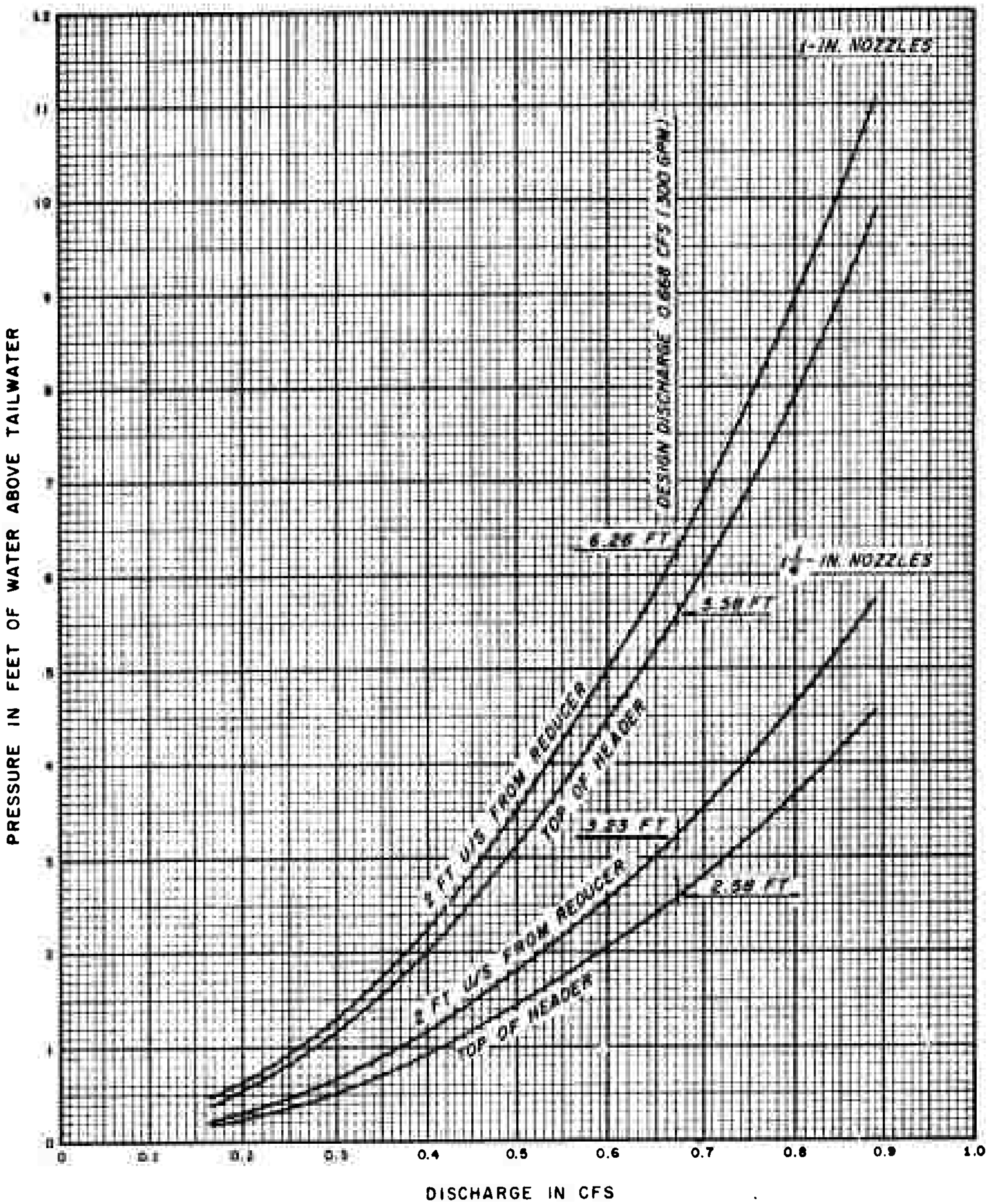
PLAN



SECTION

TEST STAND

HATCHERY JET HEADER

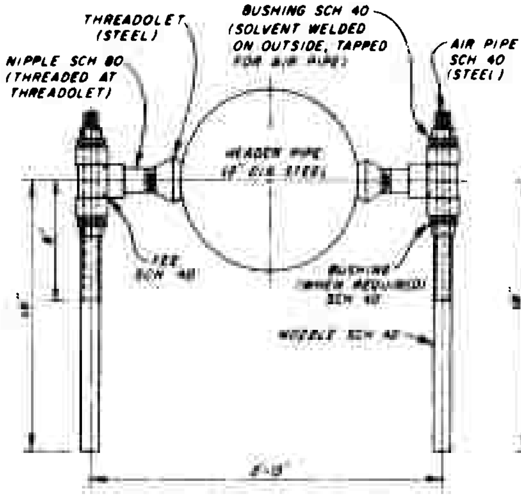


NOTE

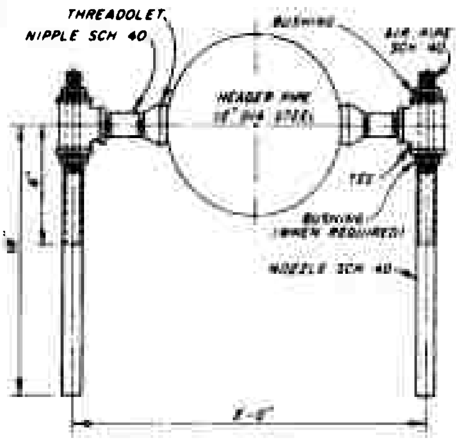
LOCATIONS OF PRESSURE TAPS AND DETAILS OF HEADER SHOWN ON PLATE 114.

PRESSURES

HATCHERY JET HEADER



PLASTIC PVC FITTINGS

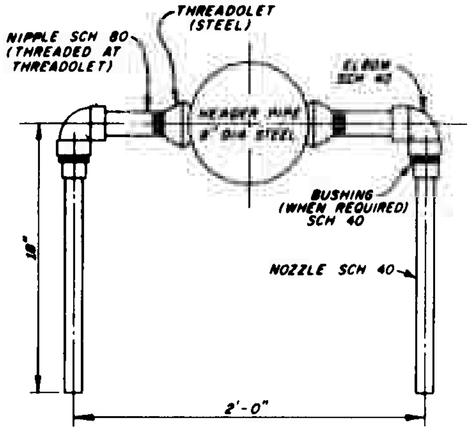


BLACK IRON FITTINGS

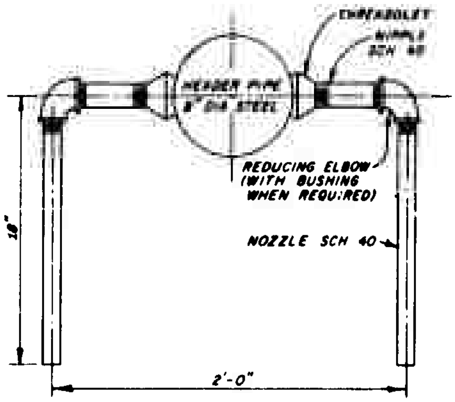
FITTINGS					
MATERIAL	AERATOR SIZE	THREADOLET AND NIPPLE	TEE	AIR PIPE	NOZZLE
BLACK IRON	1½	1½	1½	¾	1½
	2	2	2	¾	1½
	2	2	2	¾	2
	2	2	2	1	2
PLASTIC (PCV)	1½	1½	1½	¾	1½
	2	2	2	¾	1½
	2	2	2	1	2

NOTE: FITTING SIZES ARE IN INCHES.

HATCHERY AERATORS



PLASTIC PVC FITTINGS

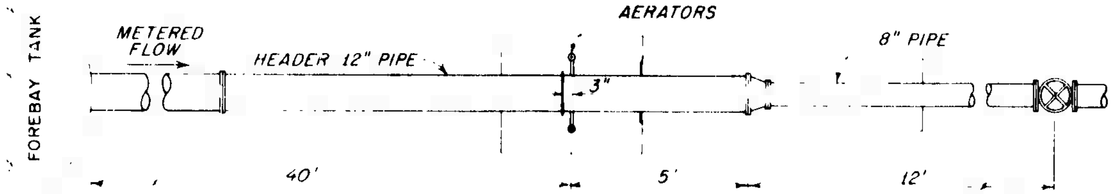


BLACK IRON FITTINGS

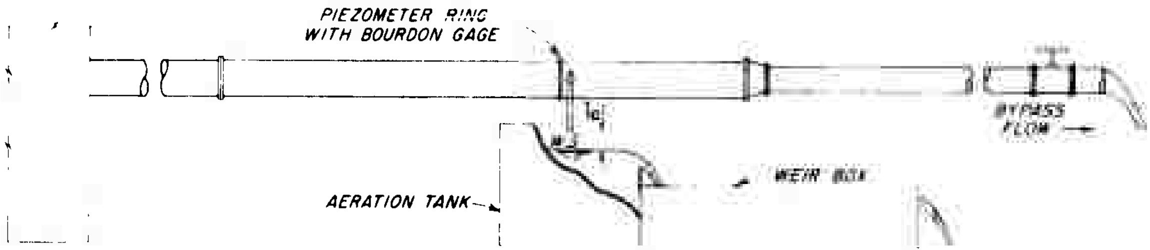
FITTINGS					
MATERIAL	DEAERATOR SIZE	THREADOLET AND NIPPLE	ELBOW	REDUCING ELBOW	NOZZLE
BLACK IRON	1½	1½	1½	-	1½
	1½	1½	-	1½ TO 1¼	1¼
	1½	1½	-	1½ TO 1	1
	2	2	-	2 TO 1½	1¼
PLASTIC (PCV)	1½	1½	1½	-	1½
	1½	1½	1½	-	1¼
	1½	1½	1½	-	1
	2	2	2	-	1¼

NOTE: FITTING SIZES ARE IN INCHES.

HATCHERY DEAERATORS

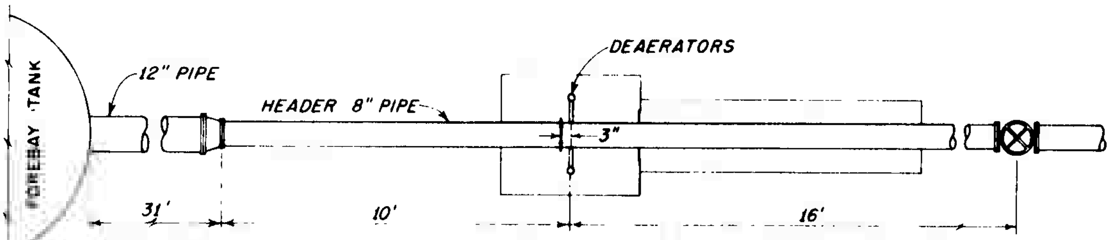


PLAN

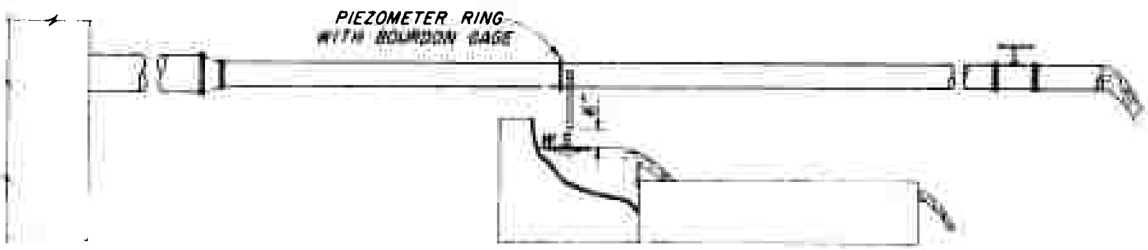


ELEVATION

AERATOR TESTS



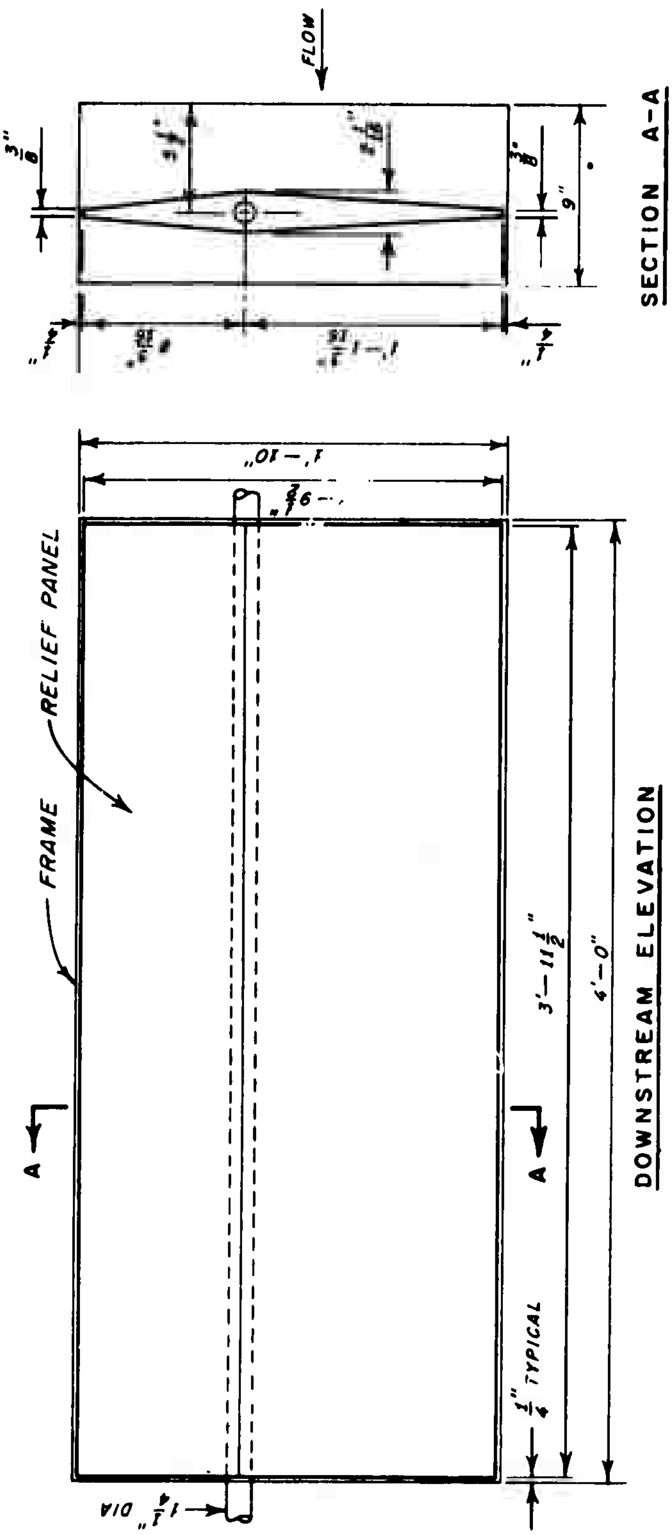
PLAN



ELEVATION

DEAERATOR TESTS

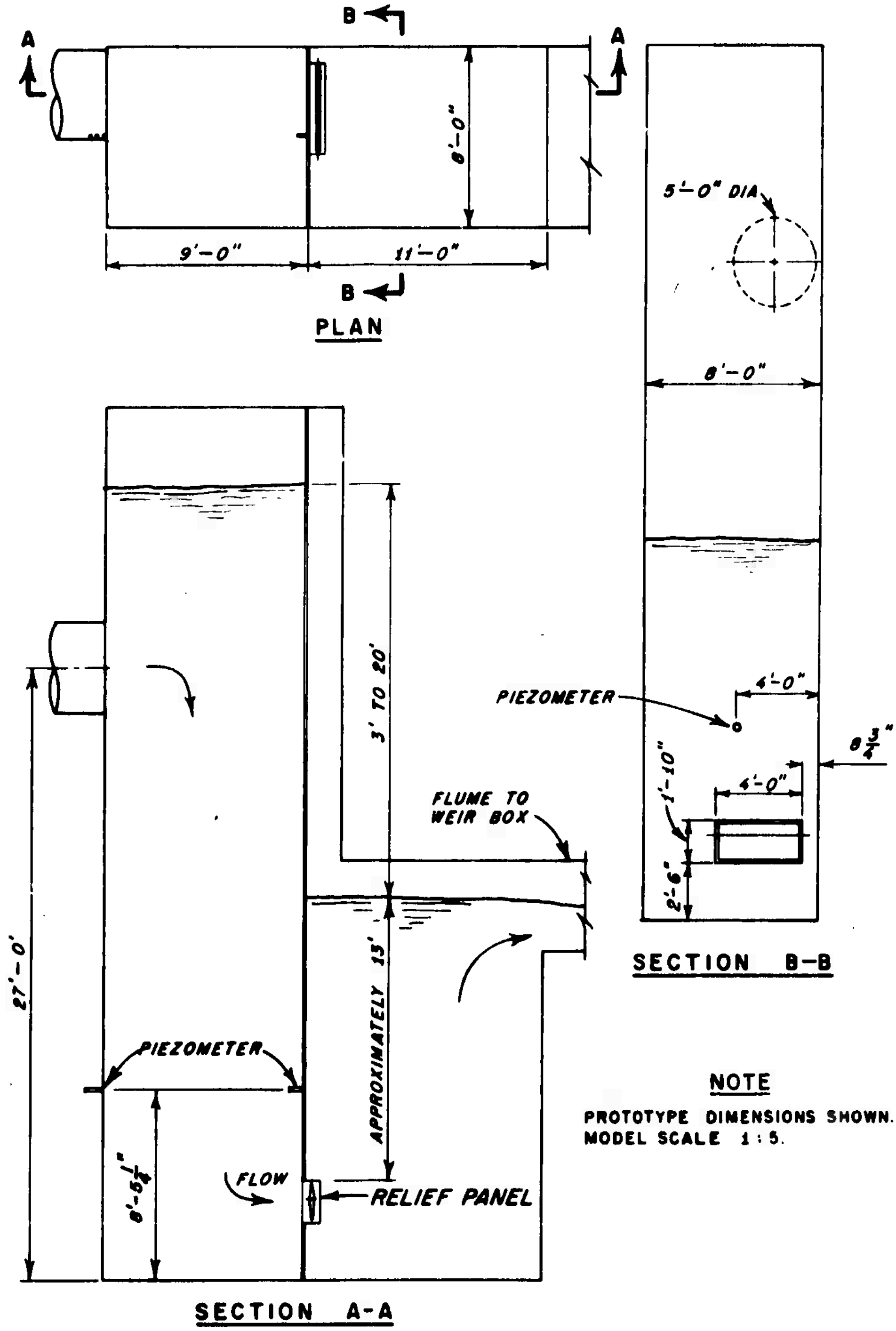
HATCHERY AERATOR AND DEAERATOR TEST STAND



SELECTOR GATE

RELIEF PANEL AND FRAME

PLATE 120

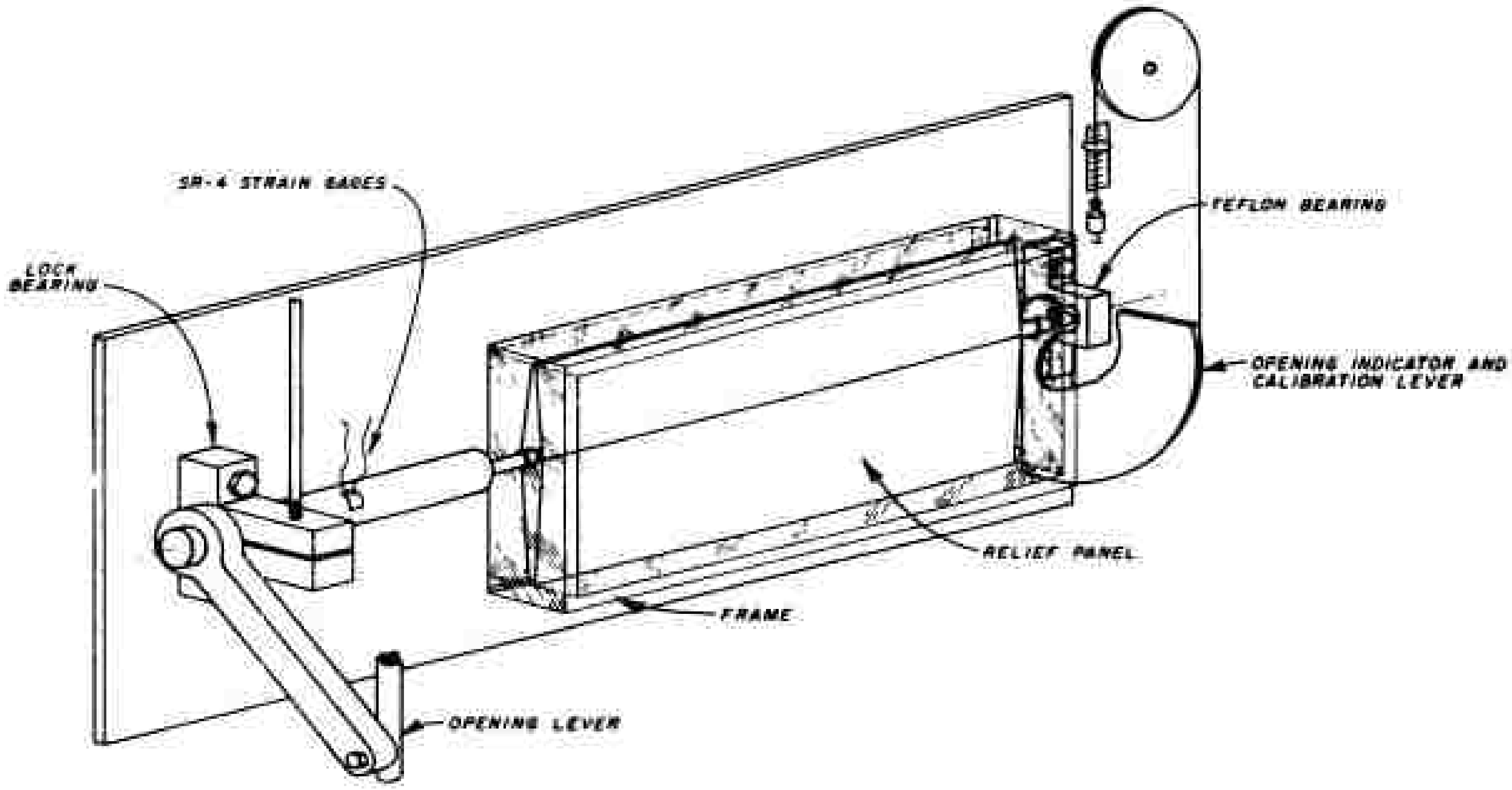


NOTE

PROTOTYPE DIMENSIONS SHOWN.
MODEL SCALE 1:5.

SELECTOR GATE

RELIEF PANEL TEST STAND

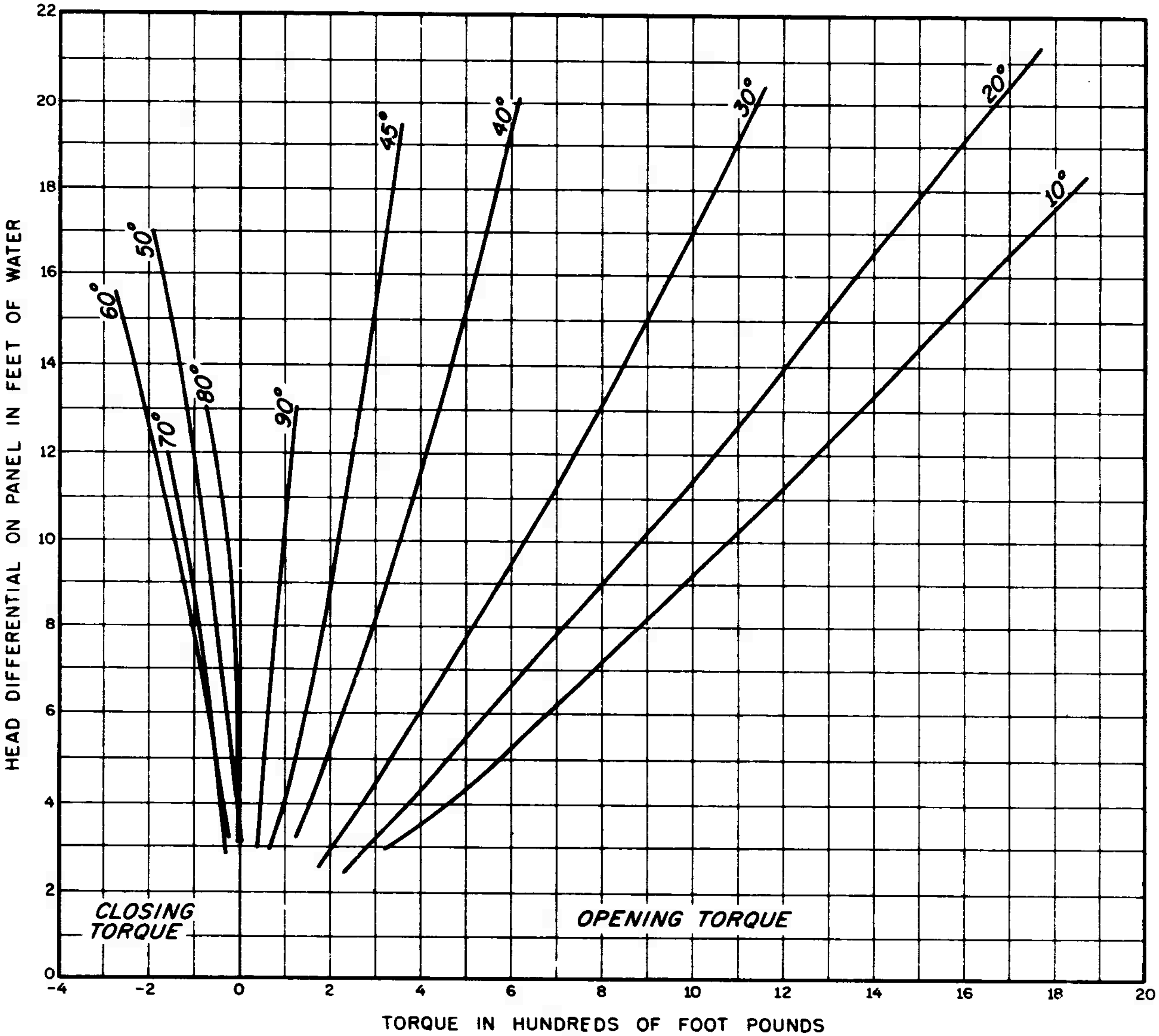


SELECTOR GATE

RELIEF PANEL

TORQUE MEASURING APPARATUS

PLATE 122

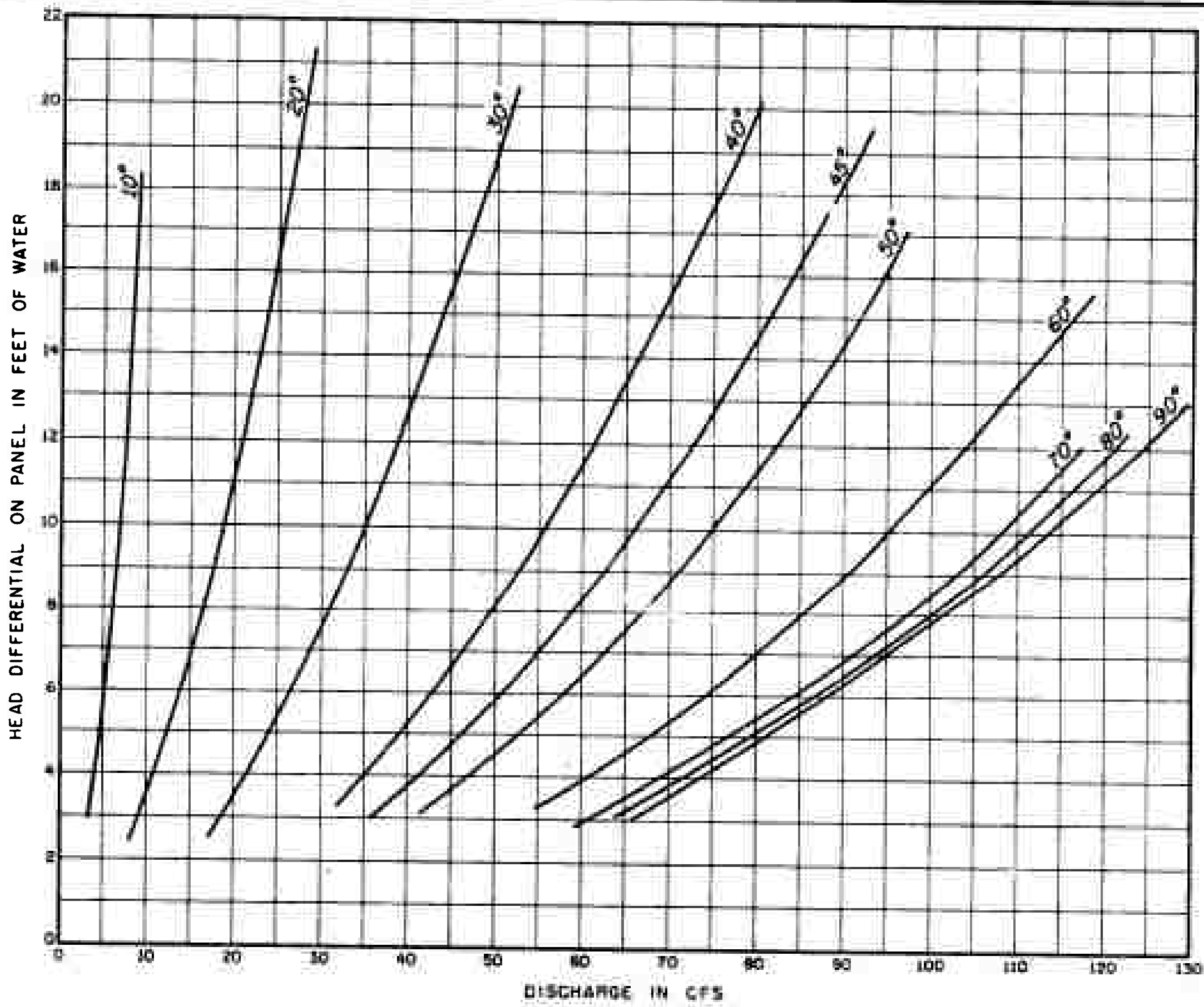


NOTES

1. DETAILS OF PANEL ARE SHOWN ON PLATE 120.
2. TORQUE MEASURING APPARATUS IS SHOWN ON PLATE 122.

TORQUE ON PANEL SHAFT

SELECTOR GATE RELIEF PANEL
PANEL OPENING 10 TO 90 DEGREES



NOTE

DETAILS OF PANEL ARE SHOWN ON 120.

DISCHARGE RATINGS

SELECTOR GATE RELIEF PANEL
PANEL OPENING 10 TO 90 DEGREES

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